

# Biology

Teaching Resource

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# Biology

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# Biology

Student Text

## 1 Biology Foundation

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# 1 Biology Foundation

## 1.1

### Cell Structure

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#### Content

- ▼ Cells as the basic units of living organisms grouped into tissues and organs.
- ▼ Characteristics of eukaryotic and prokaryotic cells.
- ▼ Detailed structure of typical animal and plant cells as seen under the light and electron microscope.
- ▼ Outline functions of organelles in plant and animal cells.

#### Learning Outcomes

Candidates should be able to:

- a) explain and distinguish between resolution and magnification with reference to light microscopy and electron microscopy.
  - b) describe and interpret drawings and photographs of typical animal and plant cells as seen using the light microscope.
  - c) describe and interpret drawings and photographs of typical animal and plant cells as seen using the electron microscope, recognising the following: rough and smooth endoplasmic reticulum, Golgi apparatus, mitochondria, ribosomes, lysosomes, chloroplasts, plasma (cell surface) membrane, nuclear envelope, centrioles, nucleus, nucleolus and cilia.
  - d) outline the functions of the following: rough and smooth endoplasmic reticulum, Golgi apparatus, mitochondria, ribosomes, lysosomes, chloroplasts, plasma (cell surface) membrane, nuclear envelope, centrioles, nucleus, nucleolus and cilia.
  - e) describe the structure of a prokaryotic cell and compare and contrast the structure of prokaryotic cells with eukaryotic cells.
  - f) explain how cells are organised into tissues with reference to squamous and ciliated epithelia, xylem and phloem.
  - g) explain the meaning of the terms tissue and organ, and state examples in animals and plants.
  - h) draw plan diagrams of tissues (including a transverse section of a mesophytic dicotyledonous leaf) and calculate the linear magnification of drawings. (*See Practical Guide*)
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## Introduction

Although the study of biology dates back to ancient Greece, it is only within the last two hundred years that the concept of the cell as the fundamental unit of life has been established, and within the past sixty years that the detailed structure of cells has been revealed. Such advances have centred on the development of microscopes with high enough magnification and resolution to allow previously hidden structures to be clearly seen. These advances have made the study of the cell (cytology) and the study of micro-organisms (microbiology) important branches of biology.

### Learning Outcome (a)

#### **RESOLUTION and MAGNIFICATION with REFERENCE to LIGHT MICROSCOPY and ELECTRON MICROSCOPY**

##### **Magnification**

For the visual study of cell structure it is necessary to enlarge (magnify) them by the use of microscopes. The **light microscopes** that you are most likely to come across in general Biology laboratories usually magnify up to  $\times 400$  (special techniques could take this up to  $\times 1000$ ). However, to continue magnifying objects past a certain point reveals no further detail. In order to see more detail it is necessary to upgrade the resolving power (resolution).

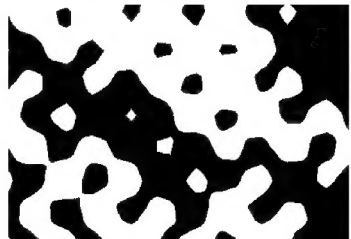
##### **Resolution**

Resolution or resolving power can be defined as the ability of an optical system (e.g. microscope, the eye) to distinguish (resolve) detail in an image of an object. More specifically resolution can be defined as the ability to distinguish between two separate points or objects.

The amount of detail that can be seen in an image is determined by the resolving power of the microscope system being used. In the case of looking at material under the light microscope the resolving power depends upon the light being able to distinguish this detail. To do this light must be reflected back from structures. Any structure less than 0.2 micrometres ( $\mu\text{m}$ ), that is 200 nanometres (nm) in diameter cannot be distinguished by light, nor can two structures closer than  $0.2\mu\text{m}$  be seen as separate.

( $1\mu\text{m}$  = one thousandth of a millimetre,  $1\text{nm}$  = one millionth of a millimetre)

To improve the resolution, it is necessary to use a device which uses a beam of electrons, instead of light, called the **electron microscope**. Electron beams have a much shorter wavelength than light and give a resolution which is 100 times better. The magnification of an electron microscope picture (electron micrograph) can also be increased significantly to reveal this extra detail. The most powerful electron microscope can magnify up to  $\times 500\,000$ .



Electron beams are disrupted by a prepared specimen and produce an image on a fluorescent screen in a similar way to a TV, or onto photographic paper to produce an electron micrograph. A vacuum is maintained inside the tube of the electron microscope so that the electron beam is not disrupted by molecules of the air e.g. oxygen and water. For this reason, it is impossible to view living specimens.

## Calculation of the linear magnification of drawings

When looking at objects under the light microscope the magnification of the object as you see it can be calculated by multiplying the magnifying power of the eyepiece lens and the objective lens (the lens close to the specimen) to get the overall magnification, for example  $\times 10$  and  $\times 40$  respectively under high power giving a total magnification of  $\times 400$ . However, when you make a drawing of a specimen seen under the light microscope, the size of your drawing further magnifies the image. To calculate the linear magnification (e.g. the number of times the length of an object has been magnified) of drawings it is necessary to measure your drawing and calculate how many times it is greater than the actual size of the object.

To calculate the actual size of the object you need to use a stage micrometer and an eye piece graticule. The **stage micrometer** is a microscope slide with a tiny ruler printed on it measuring intervals of 0.01 mm. If you could place a specimen directly on this scale could be measured directly, but this is not practicable. Therefore a glass or plastic disc with a printed scale, known as an **eye piece graticule** is mounted in the microscope eyepiece. It does not have actual measurements on it, just a scale of lines. At each magnification the number of divisions on the eye piece graticule equal to a particular real measurement on the stage micrometer is noted. For example 10 eye piece divisions will equal a larger real measurement at  $\times 100$  than at  $\times 400$ . Once this calibration has been done, the eye piece graticule alone can be used to measure the specimen.

Cheek cells are about 50  $\mu\text{m}$  in diameter, red blood cells 6-8  $\mu\text{m}$ , and some plant cells up to 500  $\mu\text{m}$ .

### ◆ CHECKPOINT SUMMARY

- ◆ Resolution is the ability to see detail.
- ◆ The higher the resolution the more of the detail that is present can be seen.
- ◆ Magnification is enlarging in size.
- ◆ Increasing magnification only reveals extra detail if the detail can be resolved.
- ◆ Resolving power of light microscope limited by the wavelength of light, put simply some detail is so small that it cannot be 'hit' by light, and therefore cannot be seen.
- ◆ Wavelengths of electron beams are much shorter than that of light and give the electron microscope greater resolving power than the light microscope, therefore extra magnification up to  $\times 250\,000$  yields an equivalent amount of detail.

### ◆ CHECKPOINT SUMMARY

- ◆ If the specimen can be observed with the naked eye without the need for magnification the calculation of the linear magnification of any drawing of it is straightforward - being the number of times any linear dimension of the drawing is greater than that of the specimen.
- ◆ Magnifications of images of slides of biological material are often given in terms relating to the magnification of the microscope image, e.g.  $\times 100$  and  $\times 400$ .
- ◆ However drawings and photographs of the image as seen down a microscope introduce another layer of magnification which is often overlooked.
- ◆ To calculate the linear magnification of drawings of microscope images of specimens it is necessary to know how many times the drawing is larger than the actual specimen.
- ◆ The actual size of the specimen is measured with an eye piece graticule and stage micrometer.

## Learning Outcome (b)

### TYPICAL ANIMAL and PLANT CELLS as seen using the LIGHT MICROSCOPE

A cell is the basic unit of structure and function in living organisms.

Many organisms are unicellular, consisting of only one independent cell, e.g. bacteria, *Amoeba* and yeast. Organisms with which we are familiar in everyday life are composed of many cells - they are multicellular.

The word 'cell' was originally used to mean a small compartment. When a slice of tissue from a plant or animal is viewed through a microscope, it is easy to see how this idea originated.

Typical animal cell features are shown by the human cheek cell. Very little detail of the structure of animal cells can be seen under the typical laboratory light microscope, in fact often only the darkly staining nucleus and paler staining cytoplasm and cell surface membrane (plasmalemma).

Plant cells are generally easier to see under the microscope, as the cell membrane of each cell is surrounded by a relatively thick **cellulose cell wall** which gives each cell a more visible boundary.

Under the light microscope several typical plant cell structures can be seen in suitably stained specimens of photosynthesising cells such as leaf palisade mesophyll cells. They have a cellulose cell wall surrounding their cell surface membrane (plasmalemma), a large central vacuole surrounded by the tonoplast membrane, numerous chloroplasts which are aligned along the elongated vertical walls in such a way as to absorb the maximum amount of light. If living cells are observed it is possible to see the chloroplasts move within the cytoplasm to positions favouring optimum light utilisation.

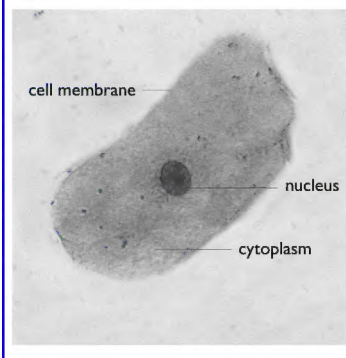
To observe more of the structure of these cells the greater resolving power (resolution) and magnification of the electron microscope is required.

Even where the magnification and resolution of a microscope are sufficient to see cells and structures, it is often difficult to actually distinguish the structures present unless the tissue is prepared in a special way. Sectioning (teasing or squashing), staining, and, in the case of permanent slides, dehydrating and mounting in a transparent resin, are involved. This should explain why professional ready-prepared slides show clear, colourful structures, whilst ones which you prepare in the laboratory are less impressive.

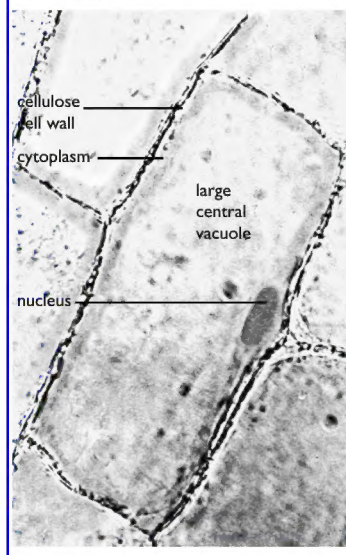
**Table of differences between typical animal and plant cells seen under the light microscope.**

| Animal cells             | Plant cells                                                 |
|--------------------------|-------------------------------------------------------------|
| Cell surface membrane    | Cell surface membrane secretes cellulose cell wall          |
| Small scattered vacuoles | Large central vacuole surrounded by membrane (tonoplast)    |
| No chloroplasts          | Chloroplasts with starch grains (in cells exposed to light) |

**Cheek lining (squamous) cell under light microscope**



**Onion epidermis cells under light microscope**



As cells in a multicellular organism become more specialised (differentiated) for particular activities e.g. transmission of impulses in nerve cells, they lose the ability to carry out some of the life processes, e.g. most nerve cells lose the ability to divide under normal circumstances. However, if some of these differentiated cells are removed from the body and kept isolated in a special culture solution they are capable of surviving on their own, and may even regain some of the lost abilities, such as the ability to divide.

Multicellular organisms may also produce single cells which can live independently, e.g. spermatozoa.

Cells which lose their nucleus cannot survive or divide, because the nucleus controls all the life processes. If an Amoeba is cut into two, the part without the nucleus dies, but the part with the nucleus lives, grows and reproduces.

**Learning Outcome (c) & (d)**

## STRUCTURE and FUNCTION of TYPICAL ANIMAL and PLANT CELLS as seen using the ELECTRON MICROSCOPE

There are two types of electron microscope. In the **transmission electron microscope (TEM)**, an extremely thin section of the specimen is held on a copper grid and the electron beam passes right through it. The electrons are disrupted by particles in the specimen. The higher their density, the greater the scattering and the lighter the resulting picture on the fluorescent screen. Pictures taken from the electron microscope are known as electron micrographs. To improve the contrast of these pictures, it is common to 'stain' the specimen with the salts of heavy metals such as lead and uranium which increase the scattering of the electrons where the 'stains' are taken up.

In the **scanning electron microscope (SEM)**, the beam of electrons passes back and forth across the surface of the prepared specimen producing a three dimensional effect. This technique is used to show surface features.

The electron microscope reveals a wealth of detail and shows the cell to be packed with a variety of structures, including membrane bound organelles, each with a particular function.

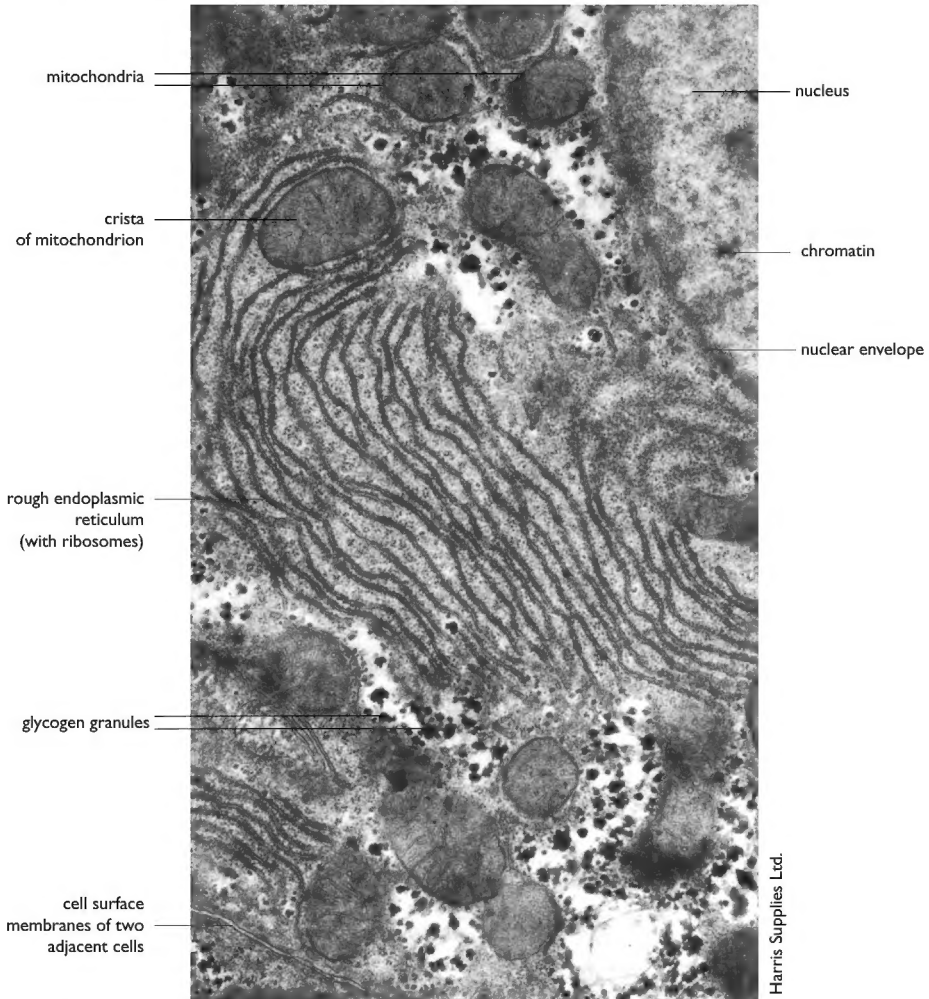
### ◆ CHECKPOINT SUMMARY

- ◆ Cell differentiation and specialisation prevent the easy definition of typical animal and plant cells.
- ◆ 'Typical' cells would be those considered to show features common to the vast majority of cells in animals or plants
- ◆ A squamous (pavement) epithelium cell from the lining of the mouth could be considered as a 'typical' animal cell.
- ◆ A mesophyll cell from a leaf could be considered as a 'typical' plant cell.
- ◆ Under the best light microscope both the typical animal cell and the typical plant cell can be seen to possess a cell surface membrane, cytoplasm, nucleus with nucleolus, mitochondria, endoplasmic reticulum, and Golgi body.
- ◆ In addition the typical plant cell can be seen to possess a cell wall around the cell surface membrane, a large central vacuole surrounded by the tonoplast membrane, and chloroplasts

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## EM part of an animal cell (liver)

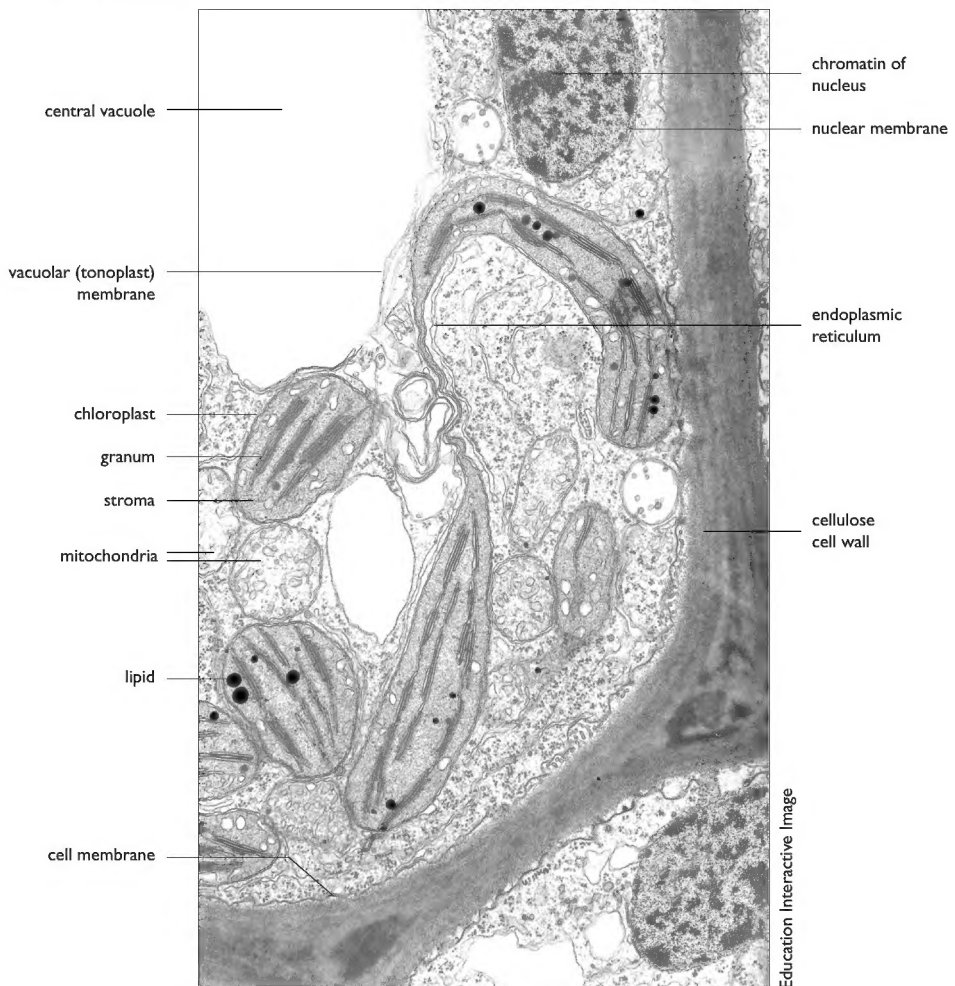


### Nucleus

Even with the optical microscope, the nucleus is clearly visible, having an average diameter in animal cells (liver) of about  $5\text{ }\mu\text{m}$ , and in plant cells (mesophyll) of about  $15\text{ }\mu\text{m}$ . The nucleus stands out because of the material **chromatin**, a mixture of DNA and protein, which takes up the stains used in slide preparations. Chromatin is the material of which the chromosomes are made. The nucleus is surrounded by a double membrane, the **nuclear envelope** which has the same structure as, and is continuous with, the **endoplasmic reticulum**. Three or four thousand large pores (up to  $100\text{nm}$  diameter) perforate the nuclear envelope but the passage of materials in and out is controlled by plugs of protein and RNA which appear to fill the pores.



## EM part of plant leaf cell



**Genes** in the nuclear chromosomes direct all the cell's activities and determine its life span and reproductive cycle. The nucleus is rightly called the command centre, but it does not contain all of the genetic material of the cell. **Mitochondria** and **chloroplasts** also contain DNA and have genes of their own.

## Nucleolus

This is an even more darkly stained region in the nucleus, which consists of a mass of RNA, used in the manufacture of **ribosomes**.

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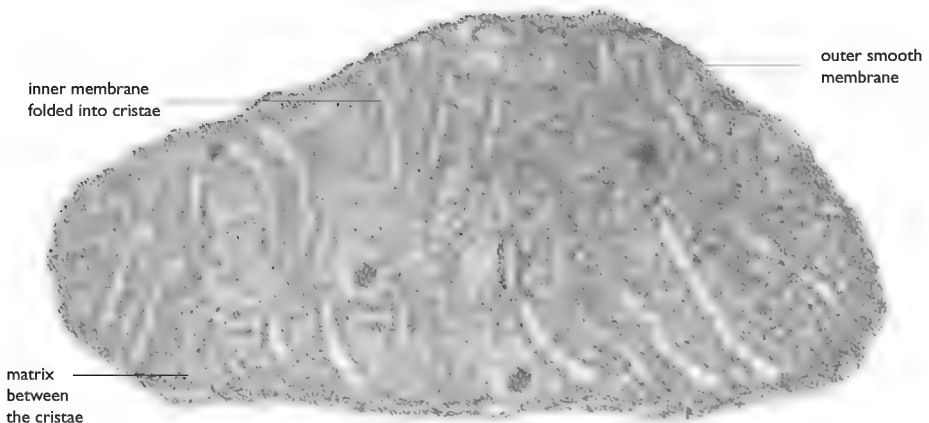
## Mitochondria - centres of aerobic respiration

Mitochondria (singular: mitochondrion) carry out aerobic respiration, which transfers energy from energy rich molecules such as glucose, into the energy rich substance ATP. High energy consuming tissues like those in the muscles or brain may contain up to a thousand mitochondria in a single cell.

Mitochondria can vary greatly in length and shape, but are never greater than  $1\mu\text{m}$  in diameter. There is an outer and an inner membrane. The area of the inner membrane is made as large as possible by infoldings of the membrane (**cristae**), and it is encrusted on its inner surface with spherical bodies which contain the enzymes for making ATP. The more active the cell, the more cristae and the more enzymes there are. In fact the more active the cell, the more the mitochondria increase in size and number by dividing.

Mitochondria and chloroplasts can be extracted from living cells by a technique called **sub-cellular fractionation**. In this process, living tissues are ground up in a blender, made up into a suspension which is placed in a centrifuge tube and then spun at high speeds in a centrifuge. Organelles of different masses separate out into layers. Those with the greatest mass (e.g. nuclei) are spun down first, and are therefore at the bottom; and those with the least mass (e.g. ribosomes) take longer to be spun down and are at the top, of the centrifuge tube contents. This method of separating different organelles has enabled their functions to be investigated, although it must be remembered that these suspensions are never completely made up of only one type of organelle. A sample of mitochondria obtained from the appropriate layer, mixed with glucose and oxygen, will produce ATP from  $\text{ADP} + \text{P}$ , indicating their role in aerobic respiration.

### Mitochondrion

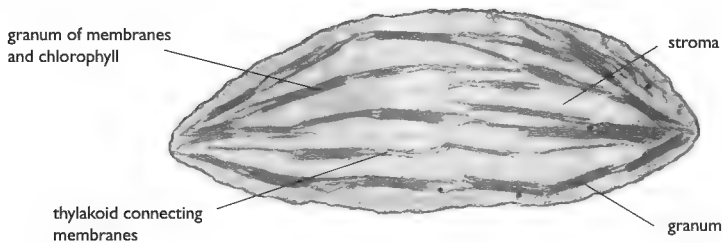


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## Chloroplasts - synthesis of organic materials

Chloroplasts contain the green pigment **chlorophyll** which absorbs light for photosynthesis. In photosynthesis light energy is used in the synthesis of organic compounds (e.g. glucose) from carbon dioxide and water. The energy is trapped in a stable form in the organic compounds. Chloroplasts, like mitochondria, have a double membrane, but there is also a third membrane system inside the chloroplast called the **thylakoid membrane system**. It is on this that the chlorophyll molecules are located. You can see from the diagram that the thylakoid membrane system is arranged in the form of stacked discs (**grana**) joined by connecting membranes (**lamellae**). The internal space is filled with a fluid (**stroma**) containing enzymes for making organic compounds, e.g. glucose and starch.

### Chloroplast



## Cytoskeleton

An interconnected system of fibrous proteins gives cells their shape and a basis for movement. A number of thread-like protein structures make up the cytoskeleton, notably **actin**, which forms thin contractile **microfilaments**; and **tubulin**, a protein which arranges itself into more rigid tubes resembling miniature scaffolding poles called **microtubules**. Microtubules form the supporting skeleton for the tiny cell 'hairs' called **cilia**. Microtubules are also formed and organised within areas called **centrosomes** which lie very close to the nucleus. During cell division, the centrosome divides to form two new centres of microtubule formation at opposite sides of the cell. A net of microtubules (**the spindle**) forms between these two new centrosomes on which chromosomes are held and pulled apart.

In animal cells (but not all plant cells) the centrosome contains two structures resembling short cilia, which can be seen in electron micrographs lying at right angles to each other. These are called **centrioles**. Centrioles also form the basal bodies at the base of cilia.

## Plasma (cell surface) membrane

This controls the movement of all substances into and out of all cells. The electron microscope does not reveal any details of its structure, which is modelled on evidence from biochemical investigations. It is fatty in nature and contains proteins and other substances. It is partially permeable, being more permeable to water, than to dissolved solutes which pass through at different rates depending on a complex of factors.

## Rough and smooth endoplasmic reticulum

In addition to the outer surface (plasma) membrane and those which surround the organelles, cells (especially secretory cells), have extensive internal membrane systems, known as the endoplasmic reticulum (ER). The **ER** is a maze of membrane bound tubules and layers of flattened sacs enclosing a fluid filled interior, which acts as an intracellular (inside the cell) transport and storage system. It is continuous with the nuclear membrane and similar in structure.

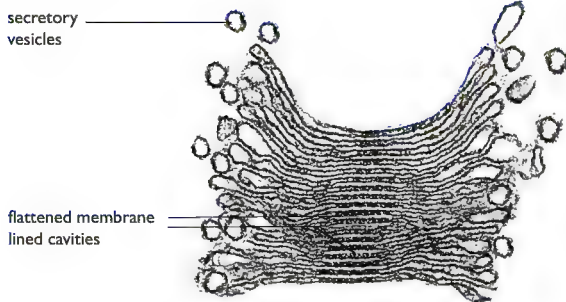
The **rough ER** has ribosomes (which are the sites of protein synthesis) associated with it on the cytoplasmic side of the membranes.

The **smooth ER** tends to be more tubular, and appears to have a complex set of functions, including fat metabolism.

## Golgi apparatus

This is more clearly seen in animal cells and is a region of stacked smooth ER specialised for the purpose of collecting, processing and redirecting proteins and fats made in the rough ER. Materials are transported between the ER, the Golgi apparatus, and the plasma membrane, sealed in membrane sacs called **vesicles** which bud off from one membrane, and then fuse with another. Substances are taken in (**endocytosis**) and expelled (**exocytosis**) by the plasma membrane in this way. For example, digestive enzymes produced by cells of the pancreas are secreted by exocytosis into the pancreatic duct.

### Golgi apparatus



## Lysosomes

Some of the vesicles produced by the Golgi apparatus are specialised for particular functions. Animal cells, have lysosomes which contain a cocktail of digestive enzymes. They break down and dispose of unwanted materials or damaged structures in the cell, expelling waste debris by exocytosis, and recycling reusable molecules within the cell. They also meet and fuse with vesicles carrying imported food substances, or immobilised bacteria, from the cell surface, and digest the contents.

If the contents of a lysosome spilled out into the cytoplasm, for example, its digestive enzymes would digest the cell itself, this process (**autodigestion**) occurs after the death of a cell and plays an important part in its removal. Therefore, it is clear from this that in the living cell the membranes surrounding lysosomes must be impermeable barriers to the passage of these digestive enzymes.

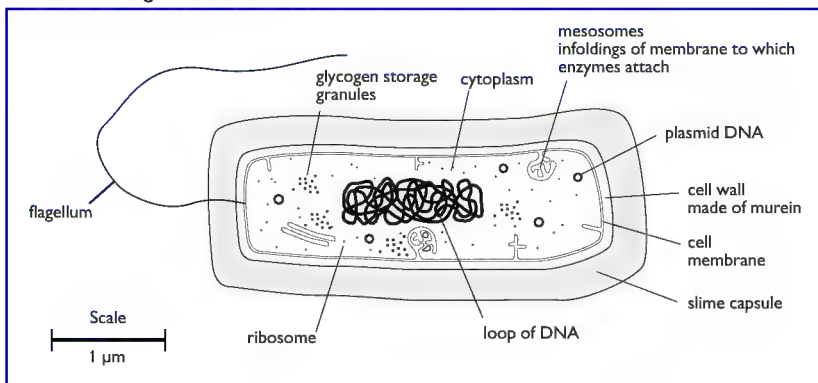
### CHECKPOINT SUMMARY

- ◆ The 'typical' animal cell under the electron microscope (EM) is the mammalian liver cell, as it contains a representative selection of those organelles found in animal cells.
- ◆ The 'typical' plant cell under the EM is a leaf mesophyll cell.
- ◆ The risk of distortion and the production of artefacts is greater with the EM as a result of the total dehydration, very thin sectioning, staining, and high temperatures generated.
- ◆ It has been argued for example that the rough or granular endoplasmic reticulum is an artefact caused by the cracking and splitting of the cytoplasm pushing the ribosomes to the edge.
- ◆ Mitochondria are rod-shaped organelles but appear oval in cross section. Chloroplasts are oval in structure and appear oval in cross section.
- ◆ The rough and smooth endoplasmic reticuli are not related in structure or function, and are not joined. Typically there is less smooth endoplasmic reticulum in plant cells.
- ◆ Smooth endoplasmic reticulum is associated with a wide range of metabolic functions.
- ◆ Controversy surrounds the identification of centrioles in plant cells.
- ◆ Lysosomes cannot be identified solely on appearance, the activity of digestive enzymes must be demonstrated biochemically.
- ◆ Functions of organelles determined by differential centrifugation, and biochemical investigation of samples from each 'organelle band', which are not completely 'pure'.
- ◆ Radioactive tracers can locate functions in specific organelles.
- ◆ Cells specialised for particular functions show organelles developed in similar way, e.g. active voluntary muscle, and secretory cells, have increased number of larger mitochondria.
- ◆ Existence of many ribosomes arranged in chains (polyribosomes) suggests protein synthesis (translation of mRNA) in action.

## The STRUCTURE of a PROKARYOTIC CELL COMPARED and contrasted with the STRUCTURE of a EUKARYOTIC CELL

The plant and animal cells which have been described so far have complex membrane systems, membrane-bound organelles, and their genetic material is enclosed within a double nuclear membrane. They are called **eukaryotic cells** ('eu' means 'true', and 'karyon' is Greek for 'nucleus'). The first organisms to develop on earth were of a simpler design similar to that of modern day bacteria. They are unicellular, much smaller than eukaryotic cells, usually not more than  $1\mu\text{m}$  wide, and their DNA is not enclosed within a nuclear membrane. They are called **prokaryotes** ('pro' means 'before').

### Generalised diagram of a bacterium



**Bacterial cell structure** of a generalised type is illustrated here in diagrammatic form. Compare and contrast this structure with that of the eukaryotic cells. Most obviously, there are no large membrane-bound organelles. Instead of mitochondria and chloroplasts, the enzymes for respiration (and photosynthesis where this occurs) are located on simple membrane systems. In the absence of a nucleus, the DNA is formed, with its associated proteins into a single main coil, the bacterial chromosome. Additional small loops of DNA called **plasmids** may also occur. Not all prokaryotes are able to move, but some possess **flagella**, which are like elongated cilia but without the microtubules, capable of propelling the organism through water. The cell wall is not made of cellulose, but is formed from a mixture of polysaccharides and amino acids called **murein**. Many bacteria which cause disease (pathogenic bacteria) have a slime **capsule** as their outermost layer which helps in protection against the body defences of the infected organism.

The diagram is generalised to show all the possible features that might occur in a prokaryotic cell. It does not represent a real organism. Prokaryotic cells generally divide and reproduce much quicker than eukaryotic cells. When grown in ideal conditions, *E. coli* can grow and divide every 20 minutes, so a single cell could theoretically give rise to  $2^{36}$  (that is a 2 with 36 noughts) in just 12 hours!

Table of principle differences between prokaryotic and eukaryotic cells

|                         | Prokaryotic cells                  | Eukaryotic cells                                                                                                                                   |
|-------------------------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Size</b>             | smaller (1-10 mm)                  | larger (10-100 mm)                                                                                                                                 |
| <b>Nucleus</b>          | no nucleus                         | true nucleus bounded by a double membrane (nuclear envelope).                                                                                      |
| <b>DNA / chromosome</b> | DNA occurs in a loop               | DNA attached to histone proteins forms separate chromosomes                                                                                        |
| <b>Organelles</b>       | simple infoldings of membrane only | chloroplasts, centrioles, microtubules may all be present endoplasmic reticulum present with Golgi apparatus and associated vesicles and lysosomes |
| <b>Cell walls</b>       | always present and made of murein  | In plants and fungi only, and made of cellulose in (plants) or chitin in (fungi)                                                                   |

#### ◆ CHECKPOINT SUMMARY

- ◆ The origin of mitochondria and chloroplasts as mutualistic prokaryotes within eukaryote cells, explains their absence in prokaryotes.
- ◆ Ribosomes present in both prokaryotic cells and eukaryotic cells.
- ◆ Prokaryotic cells may form colonies but never multicellular organisms/tissues.
- ◆ Eukaryotic cells typically form tissues in multicellular organisms.

## CELLS and TISSUES

Human cheek cells from inside the mouth come away easily because they form the outer layer of a multi-layered or compound **tissue** which is replenished continually by the formation of new cells from the base layer. Individual cells become flattened and flaky, in biological terms, **squamous**. They form an outer lining or **epithelium**, so these cells belong to a type of tissue called **squamous epithelium**. A tissue is a collection of similar cells contributing to a common function. In the case of the compound squamous epithelium - protection against mechanical damage. A different kind of epithelium, called **ciliated epithelium**, is found lining the respiratory tubes and the oviduct. The cells which make up this tissue possess cilia on their outer surface which, by their beating movements, move fluids and anything in these fluids. In the air tubes in the lungs this is important in moving dust particles and bacteria away from the air sacs (alveoli). In the oviduct they help to move eggs from the ovary to the uterus.

Plant cells are also grouped into tissues. For example the elongated cells of the **xylem** (water conducting and supporting tissue) and **phloem** (sucrose transporting tissue) are arranged end to end to form specialised vascular tissue running up and down the stem.

#### ◆ CHECKPOINT SUMMARY

- ◆ In multicellular organisms cells are organised into tissues. A tissue being an association of similar cells specialised and coordinated to a particular function. Some functions being more specialised than others.
- ◆ Examples of tissues in mammals include squamous epithelium covering surfaces e.g. in the kidney Bowman's capsule and the alveoli of the lungs, ciliated epithelium lining the trachea and bronchi, cerebro-spinal canal, and oviduct.
- ◆ Examples of tissues in plants include the transport tissues (vascular tissues) xylem (wood) and phloem.
- ◆ Some tissues consist of only one type of cell, e.g. ciliated epithelium, whilst others consist of several variants of similar types of cells, e.g. phloem tissue consists of sieve tube elements, companion cells and phloem parenchyma.
- ◆ Cells in the same tissue develop from the same original cell type, even though the fully differentiated cells may appear very different, e.g. xylem vessels and xylem parenchyma.



## TISSUES and ORGANS

**Tissues** are made up of similar cells with a common function or functions.

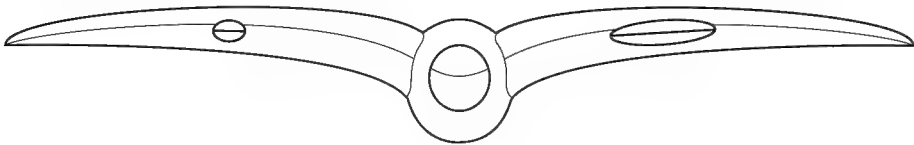
**Organs** are made up of different tissues organised to carry out a particular function or related functions, for example the leaf is an organ specialised for photosynthesis. Within it the palisade mesophyll tissue is the main photosynthetic region, the spongy mesophyll tissue aids gas exchange, and the vascular tissue allows transport of water, minerals and organic materials e.g. sucrose.

The heart is an organ specialised for pumping blood around the body, being composed of cardiac muscle, connective tissue, nervous tissue, and epithelial tissue.

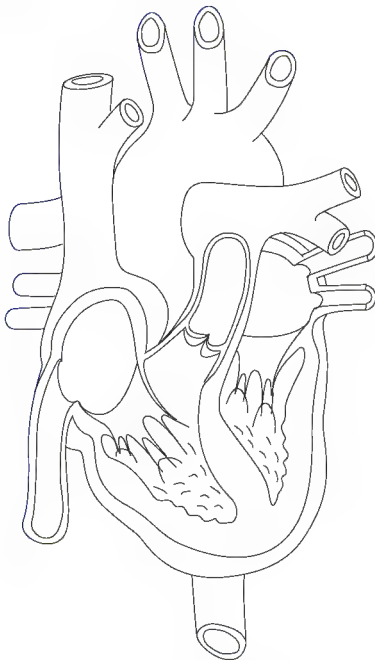
### ◆ CHECKPOINT SUMMARY

- ◆ Different tissues become 'organised' into organs specialised to particular functions, e.g. the lung is an organ and consists of squamous epithelium, ciliated epithelium, connective tissue, blood vessels etc.
- ◆ Organs are not so clearly defined in plants, but the leaf can certainly be considered as an organ of photosynthesis consisting of epidermal cells, mesophyll cells, and vascular tissue.

### Low power plan leaf (section)



### Mammalian heart



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## 1.2

# Biological Molecules

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### Content

- ▼ The structure of carbohydrates, lipids and proteins and their roles in living organisms.
- ▼ Water and living organisms.
- ▼ The roles of inorganic ions.

Candidates should be able to:

- a) carry out tests for reducing sugars and non-reducing sugars (including semi-quantitative use of the Benedict's test), the iodine in potassium iodide solution test for starch, the emulsion test for lipids, and the biuret test for proteins.
- b) describe the structures of the ring forms of alpha and beta glucose.
- c) describe the formation and breakage of a glycosidic bond.
- d) describe the molecular structure of starch (amylopectin and amylose), glycogen and cellulose, and relate these structures to their functions in living organisms.
- e) describe the molecular structure of a triglyceride and a phospholipid, and relate these structures to their functions in living organisms.
- f) describe the structure of an amino acid, and the formation and breakage of a peptide bond.
- g) explain the meaning of the terms primary structure, secondary structure, tertiary structure and quaternary structure of proteins, and describe the types of bonding (hydrogen, ionic, disulphide and hydrophobic interactions) which hold the molecule in shape.
- h) outline the molecular structure of haemoglobin as an example of a globular protein, and of collagen as an example of a fibrous protein, and relate these structures to their functions. (The importance of iron in the haemoglobin molecule should be emphasised.)
- i) describe and explain the roles of water in living organisms and as an environment for organisms. (Reference should be made to hydrogen bonding.)
- j) state one role of each of the following inorganic ions in living organisms: calcium, sodium, potassium, magnesium, chloride, nitrate, phosphate.

## Introduction

Although there are hundreds of millions of different living organisms in existence, all of them are composed of the same basic molecules. Such biological molecules rely heavily on the element carbon, along with oxygen, hydrogen and nitrogen. In fact these four elements account for 99% of all the atoms in living organisms. Two very significant features of carbon with respect to living organisms are its ability to form strong covalent bonds with other elements and to form carbon-carbon bonds, allowing the formation of large carbon based molecules in ring or chain form.

The large carbon-based biological molecules are divided into four main groups: the carbohydrates (made of carbon, hydrogen and oxygen), the lipids (also made of carbon, hydrogen and oxygen), the proteins (carbon, hydrogen, oxygen and nitrogen), and the nucleic acids (carbon, hydrogen and oxygen, nitrogen, phosphorous). In the case of the carbohydrates, proteins and nucleic acids the term macromolecules is used: this refers to the fact that these are large molecules (polymers) made up from many smaller repeated units (monomers).

In addition to the carbon based biological molecules, water (H<sub>2</sub>O) is of primary importance to all living organisms.

Learning Outcome (a) Incorporated in (b) – (f)

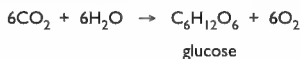
## CHEMICAL TESTS for BIOLOGICAL MOLECULES

(see Practical Guide)

Learning Outcome (b)

## STRUCTURE of the RING FORMS of ALPHA and BETA GLUCOSE

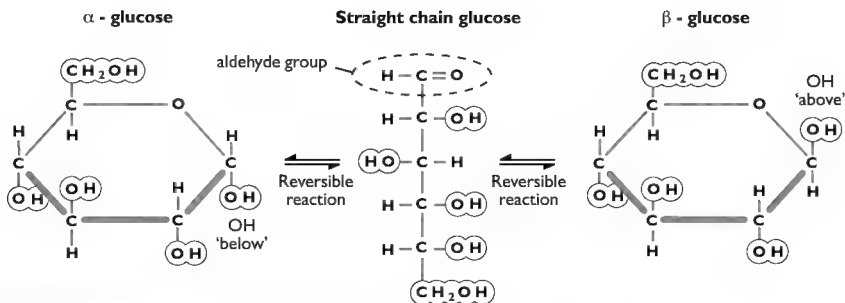
Carbohydrates are a family of molecules made up, as the name suggests, from carbon and the components of water (hydrogen and oxygen). Carbohydrates are manufactured by plants and are passed on to other organisms via food chains. You should already be familiar with the name and chemical formula of one of the simpler carbohydrate molecules, glucose, which is made from CO<sub>2</sub> and H<sub>2</sub>O in the process of photosynthesis.



Glucose has six carbon atoms in the form of a framework to which the oxygen and hydrogen atoms are attached. In dry glucose powder the carbon atoms are arranged in a straight chain, but if it is dissolved in water, the chains form themselves into ring structures. Two different ring forms exist called **alpha glucose** and **beta glucose**. The carbon atoms are numbered 1 to 6 starting in a clockwise direction from the position of the oxygen atom. As discussed later, the different structures of alpha and beta glucose result in the formation of polysaccharides with different properties.

### ◆ CHECKPOINT SUMMARY

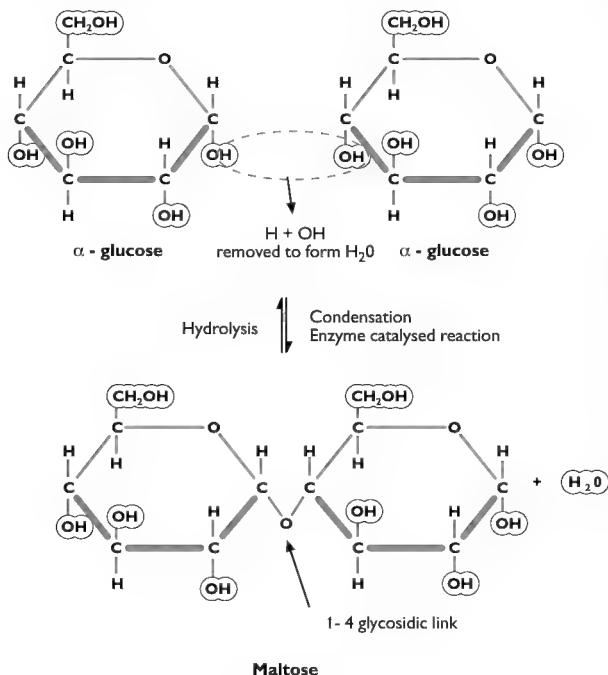
- ◆ Simple formula for glucose - C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>
- ◆ Forms straight chains in dry powder form.
- ◆ Forms ring structures in solution.
- ◆ Alpha and beta glucose are isomers differing in the 3D arrangement of their atoms.



### Learning Outcome (1)

## The FORMATION and BREAKAGE of GLYCOSIDIC BONDS

Ring structures as described above are able to link together to form pairs or long chain molecules. The terms monosaccharide, disaccharide and polysaccharide are used to describe the number of glucose molecules making up a chain (mono = 1, di = 2, and poly = many). If the units of glucose link up to form larger molecules, the first carbon atom of one alpha glucose molecule links to the fourth carbon atom of another with the elimination of a molecule of water. This enzyme controlled reaction results in an oxygen bridge called a **glycosidic bond** (an alpha 1-4 glycosidic bond) and in the formation of the disaccharide **maltose**.



The formation of bonds with the elimination of water is common in biological systems, and is known as **condensation**. The formation of more than one bond by condensation leads to longer and longer 'multi-molecules' or polymers. When molecules formed by condensation are broken down by enzymes in the body, the reverse process happens; water is added. This is called **hydrolysis**.

### Test for reducing sugars e.g. glucose

All the common simple carbohydrate sugars, with the notable exception of sucrose (table sugar), have the ability to **reduce** other chemicals. They are thus called reducing sugars and they can be identified by heating with **Benedict's reagent**. Benedict's reagent contains copper sulphate and has a clear light blue colour. This changes to brick red as the copper is reduced to a solid precipitate of copper (I) oxide in the presence of a reducing sugar. The quantity of reducing sugar in a positive test can be estimated from the amount of precipitate formed using a colorimeter or a standard colour comparison sequence.

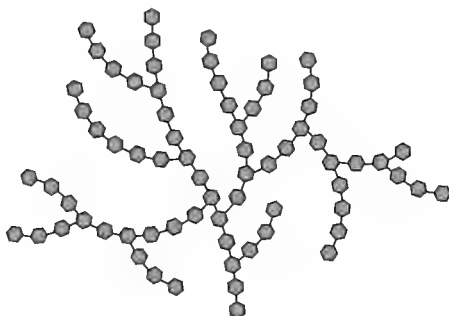
### Test for non-reducing sugars

Sucrose gives a negative result with the Benedict's test, but when heated to boiling with dilute hydrochloric acid it is hydrolysed into its constituent monosaccharides e.g. glucose and fructose, which when made alkaline and retested with Benedict's reagent give a positive result.

If a mixture of both reducing and non-reducing sugars are present, which would be highly likely with plant tissue extracts, the precipitate from the initial positive Benedict's test would need to be removed by filtration, and the resultant clear filtrate re-tested for sucrose as described above.

Glucose is the universal fuel for respiration, but it cannot be stored in cells because a high glucose concentration would result in the entry of large amounts of water by osmosis, which could cause cells unprotected by a cell wall or surrounding cells, to swell up and burst. For this reason, glucose in excess of energy requirements is converted for storage to the relatively insoluble polysaccharides **starch** in plant cells and **glycogen** in animal cells. These substances are similar in chemical structure, both being formed from chains of alpha glucose molecules.

#### Glycogen Model



#### ◆ CHECKPOINT SUMMARY

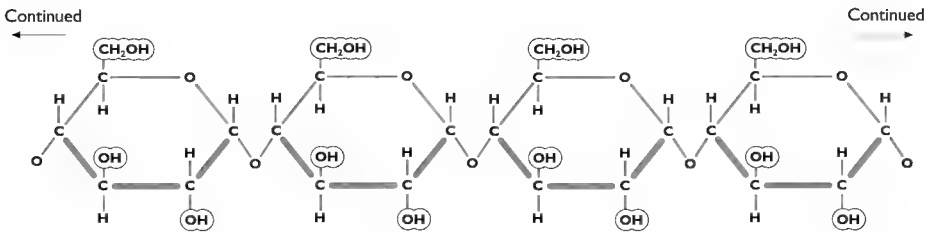
- ◆ Monosaccharides (glucose, fructose and galactose) combine together with the elimination of water to form glycosidic bonds - a condensation reaction.
- ◆ Glycosidic bonds are broken by the addition of the elements of water across the bond - a hydrolysis reaction.

## STRUCTURE and FUNCTION of STARCH, GLYCOGEN and CELLULOSE

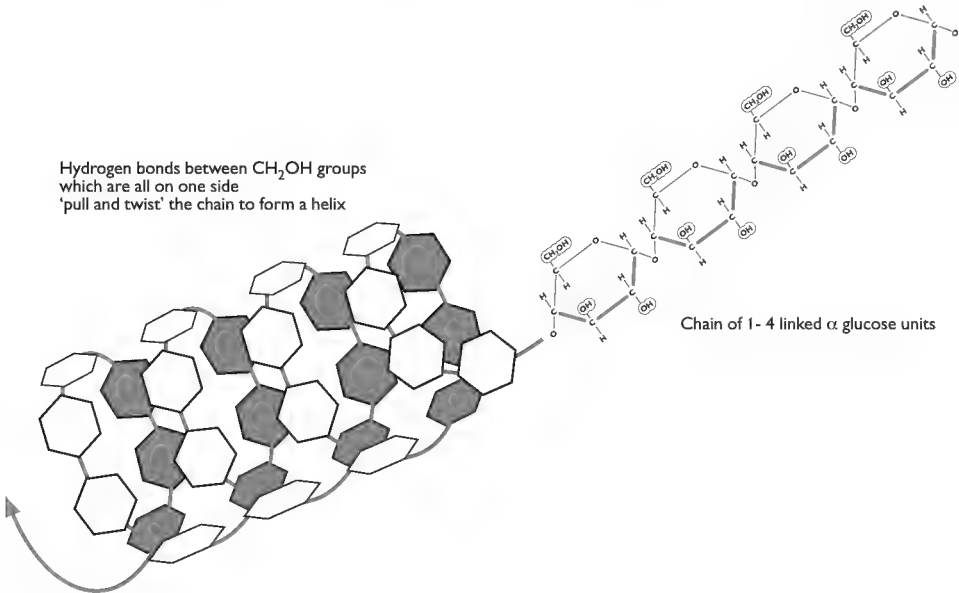
**Starch** is a mixture of **amylose** (unbranched chains of alpha glucose) and **amylopectin** (branched chains of alpha glucose). When combined together, the alpha glucose units have their oxygen bridges on the same side of the chain. Hydrogen bonds form between them and cause the chain to coil into a helix, so starch molecules have a dense, tightly packed structure and are relatively insoluble in water.

To dissolve starch, it is necessary to heat it. This breaks the hydrogen bonds and, as the coils begin to open, water molecules rush to occupy the exposed polar sites binding all over the surface. This is why starch suddenly swells in hot water and is the secret of starch based sauce thickeners used in cooking.

### Part of amylose molecule chain



Hydrogen bonds between CH<sub>2</sub>OH groups which are all on one side 'pull and twist' the chain to form a helix



## Test for Starch

A solution of iodine in potassium iodide is added to the sample at room temperature. The presence of starch is indicated by a colour change from light brown to blue-black.

## Glycogen

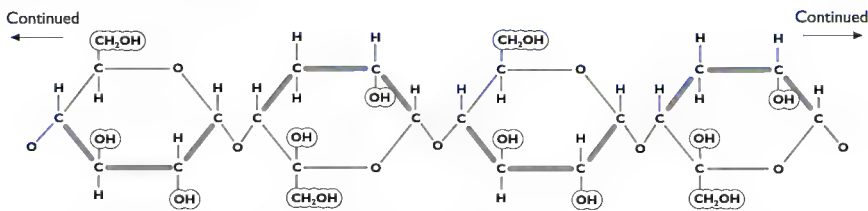
Glycogen has a similar structure to amylopectin but has a large number of shorter branches. It is more suited to animal metabolism as it is capable of being broken down more rapidly than starch.

## Cellulose

Cellulose is the major component of plant cell walls. The characteristic fibrous structure of cellulose is created by chains of 1-4 linked beta glucose molecules. The beta molecules, when joined together, have their oxygen bridges on alternate sides of the chain, and thus it cannot form into a helix, but by forming hydrogen bonds with other chains lying side by side they make flat ribbons.

The basic meshwork of cellulose fibres in plant cell walls is strengthened and cemented by other materials such as pectin, and lignin in woody tissues.

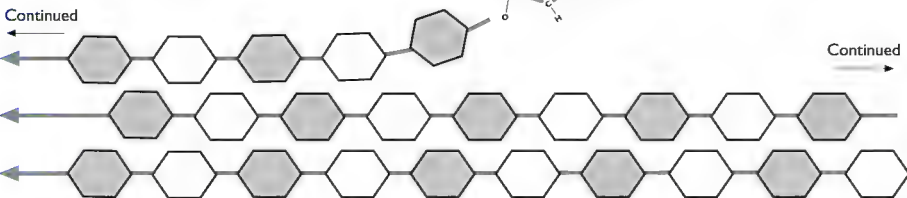
### Part of a cellulose molecule chain



Notice how the  $\text{CH}_2\text{OH}$  groups alternate from side to side of the chain (the bonds indicated by a thick line are nearer)

### Arrangement of molecules in microfibril

Chains of 1-4 linked  $\beta$  glucose units lie parallel forming a microfibril



Hydrogen bonds form between alternating  $\text{CH}_2\text{OH}$  units bind molecules together side by side into microfibrils.



Cellulose is the main component of numerous textiles e.g. cotton, linen, hemp; paper, and plastics e.g. celluloid.

Starch and cellulose have very different properties which arise as a result of one difference (the relative position of a hydrogen atom and hydroxyl group on one carbon atom) between alpha and beta glucose. Starch has no distinct structure (amorphous), no structural strength, is slightly soluble in water, and digestible by vertebrates. Cellulose has a distinct fibrous structure, great structural (tensile) strength, is insoluble in water and indigestible by vertebrates. (Herbivorous vertebrates harbour mutualistic microorganisms in specialised compartments of their gut which secrete cellulase enzyme which digests cellulose.)

Alpha and beta glucose are **isomers**; they have the same chemical formula but a slightly different arrangement of atoms in the molecule (fructose and galactose are also isomers of glucose).

#### ◆ CHECKPOINT SUMMARY

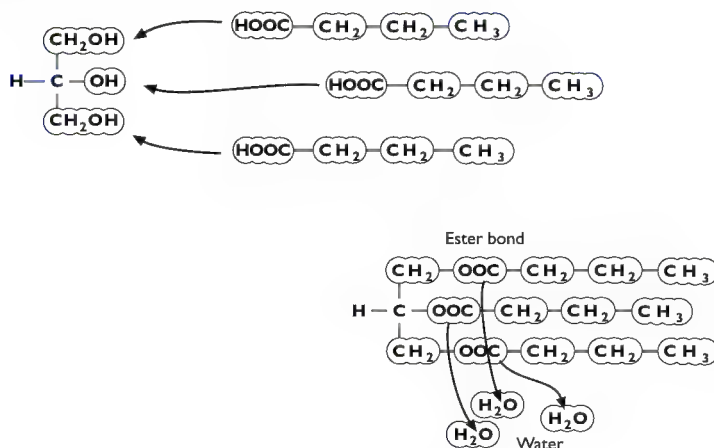
- ◆ Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains).
- ◆ Amylose and amylopectin are long chains (polymers) of alpha glucose molecules.
- ◆ When combined to form starch, the alpha glucose molecules form hydrogen bonds between themselves and cause the chain to coil into a helix, hydrogen bonds are not formed with neighbouring molecules, therefore starch has no structural strength (it is a powder).
- ◆ Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix, instead they form hydrogen bonds with other adjacent chains to make flat ribbons, therefore cellulose has great structural strength (it is fibrous).

### LEARNING OUTCOME (c)

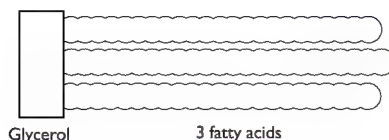
## STRUCTURE and FUNCTION of a TRIGLYCERIDE and a PHOSPHOLIPID

**Lipids** are a family of molecules which include fats, oils, waxes, phospholipids and steroids. Although they vary in chemical structure they share two important characteristics: they are energy rich substances, and they are insoluble in water.

### Molecular model of development of a triglyceride

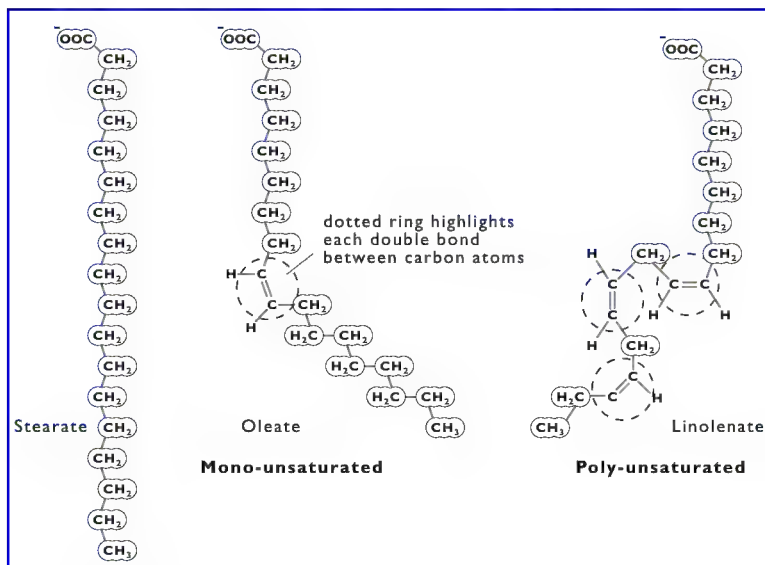


Model of a triglyceride

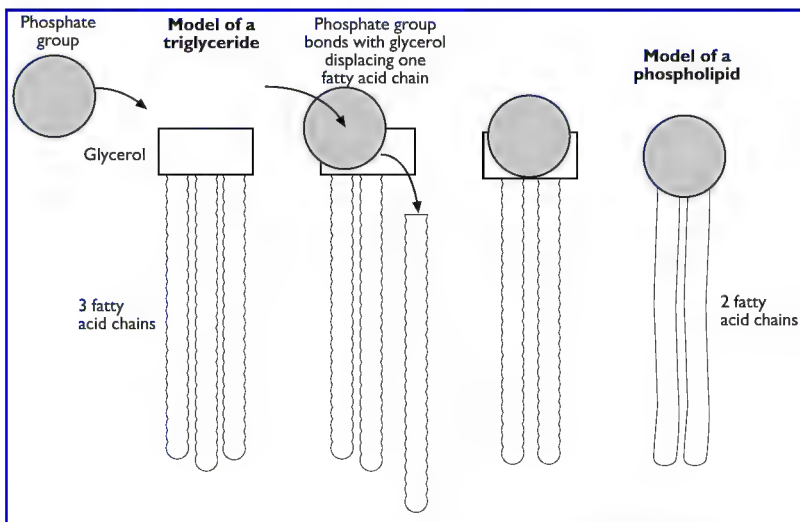


## Structure and function of a triglyceride

Fats and oils are built on the same basic chemical plan which consists of a molecule of **glycerol** joined to three **fatty acid** chains. They are **triglycerides** ('mono' and 'diglycerides' are structures with one and two fatty acid chains respectively). The fatty acids are linked by **ester bonds** to glycerol in a condensation reaction similar to that seen in the formation of polysaccharides and polypeptides.



Fatty acids are hydrocarbon chains with a carboxylic (-COOH) group at one end. It is the -COOH group which forms the ester bond with glycerol. Hydrocarbons are non-polar and, like fuel oils which have a similar structure, they contain a lot of energy locked up in their C-C and C-H bonds. Fats are mostly of animal origin and are solid at room temperature (RT); oils occur mostly in plants and are liquid at RT. The difference in melting point is due to the different nature of the hydrocarbon chains. In fats, each of the possible bonding sites between carbon and hydrogen is fully occupied (they are **saturated**), but in oils, one or more double bonds occur between the carbon atoms in the chain (they are **unsaturated**). Wherever a double bond occurs, the fatty acid chain acquires a kink, so the fatty acid chains of oils occupy more space than those of fats, giving them greater mobility and a lower melting point so that they are liquid at RT. The terms 'mono', 'di', and 'polyunsaturated' refer to the number of double bonds in the fatty acids.



When more food energy is taken in by the body than can be used, it may be converted to fat which is stored in large adipose cells under the skin and around internal organs. **Adipose** tissue not only acts as a long term food store; it also insulates the body against rapid changes in temperature, gives mechanical protection to internal organs and, acts as a buoyancy aid in aquatic animals.

Waxes differ from fats and oils in that they have only one fatty acid chain and it is not joined to glycerol, but to a longer chain alcohol. They are produced in many animals and plants as a waterproof layer on external surfaces acting to reduce water loss (e.g plant leaves, insect exoskeleton).

### Test for Lipids- the Ethanol Emulsion test

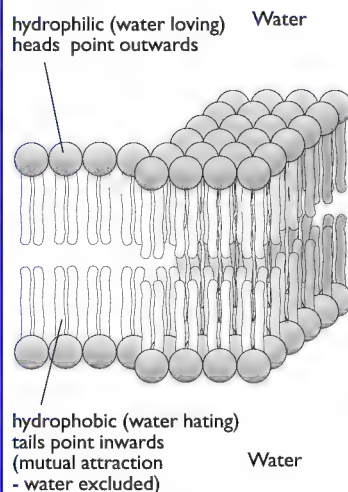
The sample is ground in ethanol to dissolve any fats and oils. 2 cm<sup>3</sup> of the filtered extract is then added to 2 cm<sup>3</sup> of water in a test tube at room temperature. The presence of lipids is indicated by the formation of a milky white emulsion.

### Structure and function of a phospholipid

Phospholipids are essential to cells because they form the structural basis of all membrane systems. They have two fatty acid chains (which may be saturated or unsaturated) joined to a molecule of glycerol, the third position being occupied by a phosphate group (phosphate plus choline or ethanolamine).

The phosphate group is strongly polar and readily dissolves in water, this is the **hydrophilic** (water loving) 'head' region of phospholipids. The non polar fatty acids are repelled by water and project in the opposite direction, and these are the **hydrophobic** (water hating) 'tails'. As a result, in the presence of water, phospholipid molecules form spontaneously into a characteristic **bilayer**. It is this bilayer which forms the molecular framework of all cell membranes.

### Phospholipid bilayer



**Cholesterol** is another important lipid component of cell membranes although it is very different in chemical structure to the lipids so far described. It has a ring structure and belongs to a group called **steroids** which include the sex hormones testosterone and oestrogen. Cholesterol molecules are strongly hydrophobic and they take refuge between the tails of phospholipids in membranes. Their presence in the bilayer has two effects. It slows down the lateral movement of individual phospholipid molecules, making the bilayer more stable, and it prevents the movement of certain substances through the bilayer, ensuring that membrane transport occurs through the correct (protein) channels.

#### ◆ CHECKPOINT SUMMARY

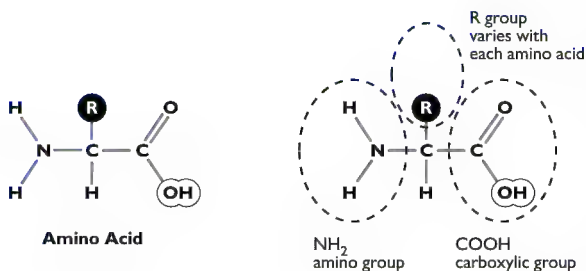
- ◆ Triglycerides are composed from three (tri) fatty acids combined by condensation reactions to form ester bonds with glycerol.
- ◆ Fatty acids have long hydrocarbon chains and a carboxylic group ( $\text{COOH}$ ).
- ◆ Saturated fatty acids (and hence saturated fats) have no double bonds in the hydrocarbon chain which is 'saturated' with hydrogen.
- ◆ Unsaturated fatty acids have one double bond.
- ◆ Polyunsaturated fatty acids have two or more double bonds.
- ◆ Lipids include fats, oils, waxes, phospholipids and steroids.
- ◆ Fats (triglycerides) are energy rich storage products in plants and animals.
- ◆ Phospholipids are formed from triglycerides by the replacement of one fatty acid by a phosphate group.
- ◆ Phospholipids form the structural basis of biological membranes by forming a bilayer.
- ◆ The bilayer is formed with their hydrophobic poles adjacent and their hydrophilic poles in contact with the aqueous phase.

### Learning Outcome (1)

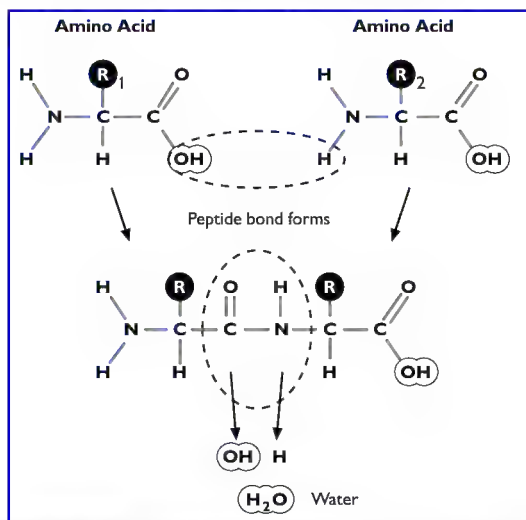
## STRUCTURE of AMINO ACIDS and the FORMATION and BREAKAGE of a PEPTIDE BOND

The chemical structure of an amino acid consists of a central carbon atom bonded to a hydrogen atom, a carboxyl group ( $-\text{COOH}$ ), an amino group ( $-\text{NH}_2$ ), and a side chain which varies with each amino acid, referred to as the 'R' group.

#### Structure of an amino acid



**Peptide bonds** form between the amino ( $\text{-NH}_2$ ) and carboxyl ( $\text{-COOH}$ ) groups of adjacent amino acids to make chains called peptides (dipeptide = 2 amino acids linked together, polypeptide = many amino acids). As in carbohydrates, these linkages are made by a condensation reaction involving the elimination of a molecule of water.

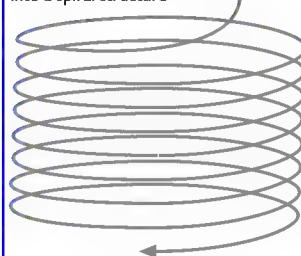


#### ◆ CHECKPOINT SUMMARY

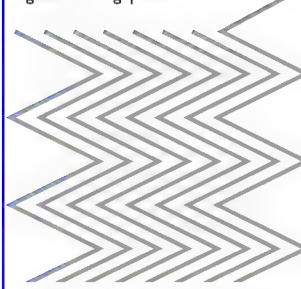
- ◆ All amino acids share a common structure consisting of a hydrogen atom, an amino group ( $\text{NH}_2$ ), a carboxyl acid group ( $\text{COOH}$ ), and a 'R' group, all attached to a carbon atom.
- ◆ The 'R' group can range from a single hydrogen atom to a long complex chain. Thus the simplest amino acid has the formula of  $\text{CH}_2\text{NH}_2\text{COOH}$ .
- ◆ Amino acids combine in a condensation reactions which form peptide bonds.
- ◆ There are about 20 different types of amino acids found in proteins of living organisms.
- ◆ Proteins are polymers of up to 2000 amino acids joined by peptide bonds (polypeptides)
- ◆ The combination of the 20 different types of amino acids gives rise to as many as 100 000 different types of proteins in living organisms.

#### Secondary structure of proteins

In an alpha helix hydrogen bonds 'pull' molecule chain into a spiral structure



In a beta sheet hydrogen bonds hold and align molecule chains side by side. Angle of bonds in each chain are as a consequence perfectly aligned forming 'pleats'.



#### Learning Outcome (s)

### STRUCTURE of PROTEINS

Proteins are polymers made up of **amino acids**, joined together in long chains, which may be folded and twisted in various ways. There are as many as 100 000 different kinds of protein molecules in human cells. This variety of structure is made possible by the fact that the twenty different types of amino acids commonly found in proteins can be arranged in any order in chains up to 2000 units long.

#### Primary structure

The amino acid sequence is the starting point or primary structure of proteins. The final shape of proteins depends upon additional bonds which form between the  $\text{-NH}$ ,  $\text{-C=O}$ , and  $\text{-R}$  groups which 'stick out' of the sides of the polypeptide chain.

#### Secondary structure

The secondary structure of proteins is determined by hydrogen bonds between adjacent  $\text{-NH}$  and  $\text{-C=O}$  groups. Two very different formations are possible, the **alpha helix** and **beta sheet**. Both of these secondary structures may occur in the same protein

#### Tertiary structure

The tertiary (third level) structure of proteins is determined by bonds which form between R groups. There are three possible types depending upon the chemical properties of the different  $\text{-R}$  groups.  $\text{-R}$  groups may be acid, basic, polar or non polar.

## Quaternary structure

The quaternary (fourth level) structure of proteins arises from the combination of separate polypeptide chains to form a larger complex, e.g. haemoglobin, which is composed of four polypeptide chains with iron containing haem units.

## Types of bonding which hold protein molecules in shape

**Hydrogen bonds** are formed between polar -R groups (in addition to the H-bonds already described)

**Ionic bonds** are formed between the negatively charged acidic -R groups and positively charged basic -R groups. The forces are like those which exist between the  $\text{Cl}^-$  and  $\text{Na}^+$  ions in salt.

**Hydrophobic bonds** occur between the -R groups of non polar amino acids e.g. valine (Val) and leucine (Leu).

**Disulphide bridges** are much stronger covalent bonds formed between the sulphur atoms of the amino acid cysteine (Cys).

Proteins may be modified further by being linked to mineral ions, as in the case of haemoglobin or joined to carbohydrates and lipids to form **glycoproteins** and **lipoproteins**. This 'finishing off' process happens within the endoplasmic reticulum of cells.

## Test for Protein - the biuret test

2cm<sup>3</sup> of potassium hydroxide is added to 2 cm<sup>3</sup> of the sample in a test tube followed by a few drops of dilute copper sulphate solution. The presence of protein is indicated by a change in colour from light blue to purple.

## Learning Outcome (2)

## STRUCTURE and FUNCTION of GLOBULAR and FIBROUS PROTEINS

Proteins may be either globular or fibrous in their final form.

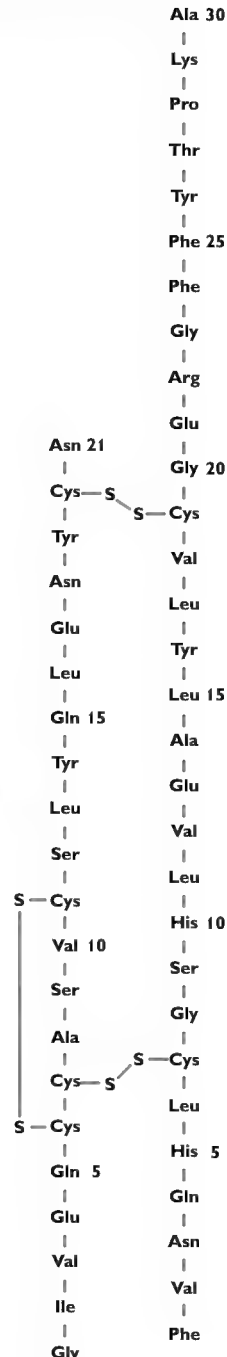
## Globular proteins

Globular proteins have a pronounced tertiary structure with many folds and twists, making them very susceptible to temperature and pH changes. Non polar groups tend to be repelled by water (hydrophobic) and tuck inside the molecule whilst the polar groups are attracted to water (hydrophilic) and they face outwards forming hydrogen bonds with water molecules. Globular proteins therefore tend to be soluble. Globular proteins are involved in metabolic activities e.g. enzymes, hormones, antibodies, and haemoglobin.

## Haemoglobin

Haemoglobin, the molecule responsible for carrying oxygen in red blood cells was one of the first proteins whose structure was examined in detail. It is a globular protein made up of four polypeptide chains: two are 114 amino acids long, and two 146 amino acids long. Each chain is associated with a 'haem' group containing iron and contains one oxygen binding site. Oxygen is

## Disulphide bridges

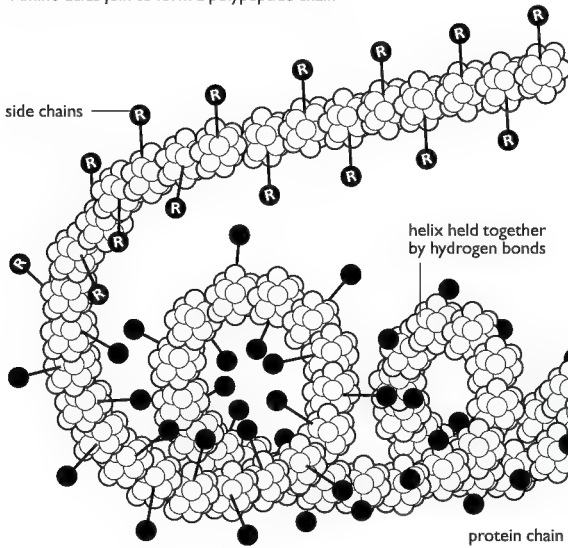


carried around the body as oxyhaemoglobin, a reversible compound which forms when oxygen concentration is high and splits up when oxygen concentration is low. The four chains cooperate with each other in such a way that the binding of one oxygen molecule to one chain increases the efficiency of oxygen binding to the other chains. This is significant in the oxygen dissociation curves discussed in section 5.2.3. Slight changes in the structure of the haemoglobin molecule caused by mutations of the haemoglobin genes reduce its efficiency in oxygen transport and lead to various types of anaemia.

#### Diagram showing the structure of haemoglobin

##### Primary structure

Amino acids join to form a polypeptide chain

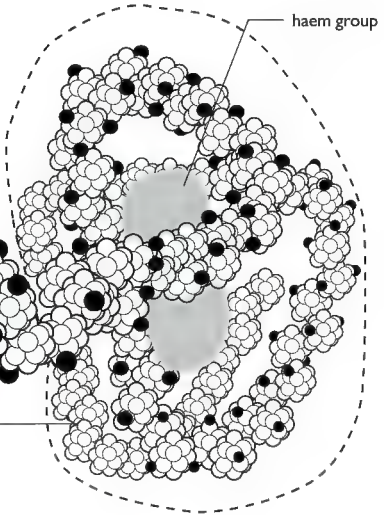


##### Secondary structure

Polypeptide chain folds in upon itself to form a helix

##### Tertiary structure

Helix folds to form compact globular unit around Haem group



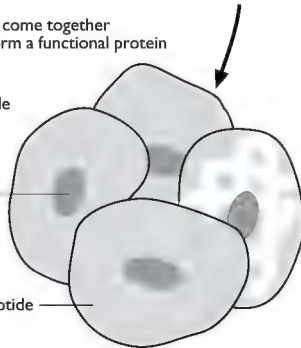
##### Quaternary structure

Several polypeptide chain units come together held by disulphide bridges to form a functional protein

Haemoglobin molecule has four subunits

haem group

globular polypeptide subunit





## Fibrous proteins

In fibrous proteins the peptide chains are extended and inter-twined to form long thread like molecules. They do not dissolve in water and are relatively unaffected by changes in pH or temperature (they are not easily denatured). Fibrous proteins are mainly structural in function, giving support to tissues e.g. keratin in hair, and collagen in the skin.

## Collagen

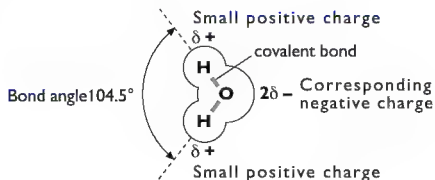
is the most important structural component of skin, bone and tendons. It is the collagen in skin which forms leather after treatment in the tanning process, and it is collagen which gives bones their 'bendability'. Bone without collagen is like concrete without the reinforcing steel rods. The word 'collagen' is Greek for 'glue maker' because it was extracted from bones by boiling them up in water and used as a strong wood glue. Chemically, collagen molecules are made up of three polypeptide chains, each consisting of about 1000 amino acid units which twist around each other like the strands of a rope (a triple helix). The molecules of collagen are insoluble and have a natural tendency to link up with each other forming fibrils several millimetres long.

## Learning Objective 5

### STRUCTURE and ROLES of WATER

Almost everyone 'knows' the chemical formula for water,  $H_2O$ . It is a molecule made up of two hydrogen atoms combined with a single oxygen atom. As molecules go  $H_2O$  appears rather simple, yet its molecular structure results in many unique properties upon which life depends.

#### Molecular model of water



Electron distribution within the water molecule causes the oxygen end of the molecule to have a partial negative charge and the hydrogen sites to have a partial positive charge

Each hydrogen atom combines with the oxygen atom by means of a pair of shared electrons (covalent bond). The nucleus of the oxygen atom has a strong positive charge which tends to pull the negatively charged electrons away from the smaller hydrogen atoms. As a result, a partial negative charge develops near the oxygen atom and partial positive charges occur near the hydrogen atoms. Molecules which have charged regions are called **polar molecules**. Water has both partial positive and negative charges and is therefore described as **dipolar**.

#### ◆ CHECKPOINT SUMMARY

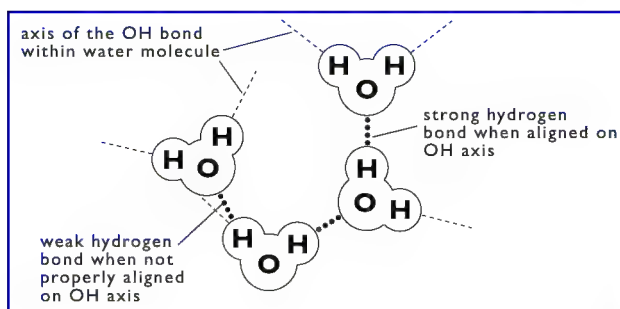
- ◆ The sequence of amino acids in the polypeptide chain determines the primary structure of proteins.
- ◆ Hydrogen bonds between adjacent  $NH_2$  and  $COOH$  groups result in the secondary structure of either alpha helix or beta sheet. Both of these structures may occur in the same protein.
- ◆ Bonds that form between the 'R' groups determine the tertiary structure.
- ◆ Combination or association of two or more polypeptide chains determines the quaternary structure of a protein.
- ◆ Haemoglobin has a quaternary structure involving four polypeptide chains and four iron containing haem groups.

#### ◆ CHECKPOINT SUMMARY

- ◆ Water molecules are dipolar with an electronegative pole and an electropositive pole.
- ◆ The dipolar nature of water causes molecules to be attracted to each other by hydrogen bonds resulting in most of the key properties of water in relation to living organisms.



The partial positive and negative charges cause water molecules to attract each other by means of relatively loose linkages called **hydrogen bonds** (H-bonds). This mutual attraction explains why water is a liquid at standard temperature and pressure (STP), whereas other, similar sized, non-polar molecules like methane ( $\text{CH}_4$ ), ammonia ( $\text{NH}_3$ ) and hydrogen sulphide ( $\text{H}_2\text{S}$ ) are gases. The H-bonds in water are broken when energy is supplied, e.g. when water is heated. When they break the liquid becomes a gas (vapour). At and below  $0^\circ\text{C}$  the H-bonds are at their shortest and strongest and lined up to form an open regular crystalline structure which is ice. Crucially for life on earth, ice is less dense or 'lighter' than liquid water; in other words ice floats, and aquatic organisms are protected beneath an insulating layer of surface ice. If it did not, and water froze from the bottom up, aquatic organisms would be exposed in progressively shallow surface waters.



Water molecules also attract other polar molecules. When mixed with salt ( $\text{Na}^+\text{Cl}^-$ ), for example, weakish electrostatic links are made between the positive and negative charges of the salt and the water. Water is an excellent solvent allowing many molecules and charged ions to be held in cells and transported around the body. Any molecule with a polar region will dissolve, including sugars and alcohol, and water molecules gather around large protein molecules to form a special kind of solution called a **colloid**, as found in the cytoplasm of cells.

As you have seen, the chemical structure of water determines its properties. The following table lists these properties with examples of their biological importance.

#### Molecular model of water solubility

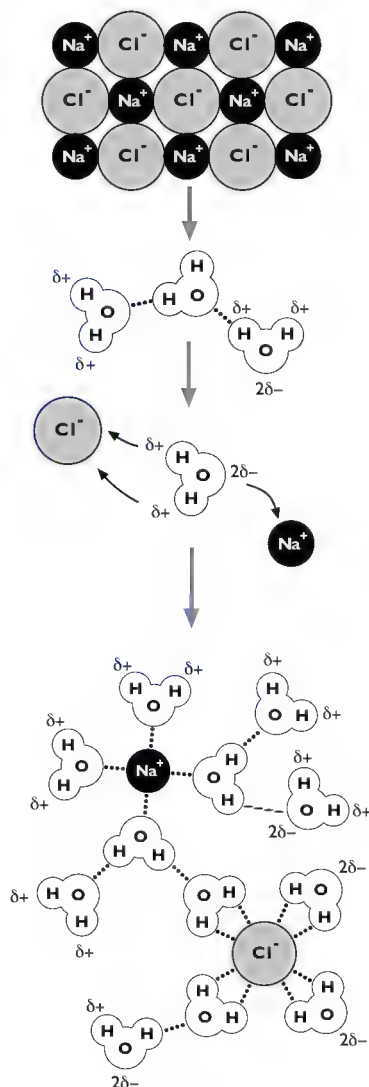


Table of principal properties of water and their biological importance

| Property                   | Example of Biological Importance                                                                                                                                                                                               |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| State                      | Solid (ice) at 0°C and vapour above 100°C (at sea level), providing a wide range of temperature at which it exists as a liquid.                                                                                                |
| Solvent                    | 'Universal' solvent in which many substances dissolve.                                                                                                                                                                         |
| Density                    | Water supports aquatic organisms. Ice is less dense than water, therefore ice floats and organisms can survive beneath it.                                                                                                     |
| Viscosity                  | Allows free flow for transport of materials inside and outside of organisms.                                                                                                                                                   |
| Surface Tension            | Water has a strong surface film allowing small organisms to be supported on top or underneath it.                                                                                                                              |
| Capillarity                | Water rises in small bore tubes against the pull of gravity because the polar water molecules are attracted to themselves and to a number of surfaces. Capillarity is important in water transport in plants.                  |
| Incompressibility          | Water provides a hydrostatic skeleton. When enclosed in any structure with a strong surrounding wall, water provides much support and protection to structures within it - e.g. earthworm body cavity, human abdominal cavity. |
| Latent heat of evaporation | As they evaporate water molecules absorb heat energy from evaporation surfaces, cooling them down in the process e.g. sweating.                                                                                                |
| Specific heat              | Water has a high specific heat. This means that it gains and loses heat slowly which is important in temperature control of aquatic environments and internal fluids.                                                          |
| Transparent                | Allows the transmission of light e.g. for photosynthesis in aquatic organisms.                                                                                                                                                 |

## Learning Objective 11

### ROLE of INORGANIC IONS in LIVING ORGANISMS

Water, carbohydrates, proteins and fats account for 99% of our body mass and are needed in relatively large quantities in the diet. Inorganic ions are needed in much smaller quantities, in some cases just a few milligrams, but they are just as important. You have already seen how iron ions are essential to the haem part of haemoglobin. In a similar way, magnesium ions ( $Mg^{2+}$ ) are essential to the chlorophyll molecule in plants. Nitrate ions ( $NO_3^-$ ) are needed by plants in order to supply the amino ( $-NH_2$ ) group of amino acids. Phosphate ions ( $PO_4^{3-}$ ) are required to make phospholipids. Phosphate ions are also important in bone, being deposited with calcium ions ( $Ca^{2+}$ ) around the collagen fibres to make a hard skeletal material.

In later sections you will appreciate how important sodium ( $Na^+$ ), potassium ( $K^+$ ), and chloride ( $Cl^-$ ) ions are in maintaining the correct electrical and osmotic relations across cell membranes. In our own bodies the liver and kidney play very important roles in controlling the balance of all these inorganic ions (electrolytes), keeping them within very precise limits for the correct functioning of the body's chemical machinery.

## 1.3

### Enzymes

#### Content

##### ▼ Mode of action of enzymes

Candidates should be able to:

- explain that enzymes are globular proteins which catalyse metabolic reactions.
- explain the mode of action of enzymes in terms of an active site, enzyme/substrate complex, lowering of activation energy and enzyme specificity.
- describe and explain the effects of pH, temperature, enzyme concentration and substrate concentration on enzyme action.
- follow the time course of an enzyme-catalysed reaction by measuring rates of formation of products (for example using catalase), or rate of disappearance of substrate (for example using amylase).
- explain the effects of reversible inhibitors (both competitive and non-competitive) on the rate of enzyme activity.

#### ENZYMES as GLOBULAR PROTEINS which CATALYSE METABOLIC REACTIONS

Most students of science can name an enzyme. Usually it is a digestive enzyme like amylase or pepsin, but enzymes are not just concerned with breakdown reactions like digestion, they can also help build things up. In fact, every chemical reaction in every living cell is made possible by an enzyme. Several thousand enzymes have been isolated and studied.

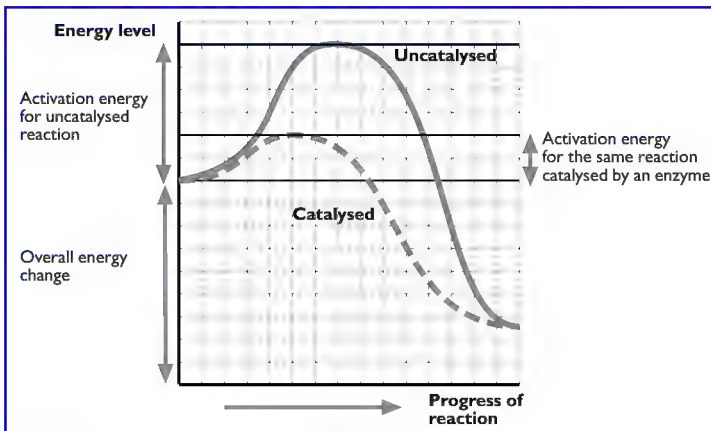
Enzymes are protein molecules. Compared to many other molecules they are relatively large (macromolecules) of the globular type. Enzymes are **biological catalysts**. A catalyst is a substance which speeds up a reaction without being changed itself in the process. As they are not used up or changed, enzymes can be used repeatedly; therefore they are effective in relatively small amounts.

#### MODE of ACTION of ENZYMES in terms of an ACTIVE SITE, ENZYME/SUBSTRATE COMPLEX, LOWERING of ACTIVATION ENERGY and ENZYME SPECIFICITY.

Usually enzyme molecules are much larger than the reacting molecules (substrates). In an enzyme-catalysed reaction, the substrate(s) become attached to a particular region on the enzyme called the **active site** which has a specific shape and structure matching that of the substrate(s), forming the **enzyme - substrate complex**. This association is temporary and lasts only long enough

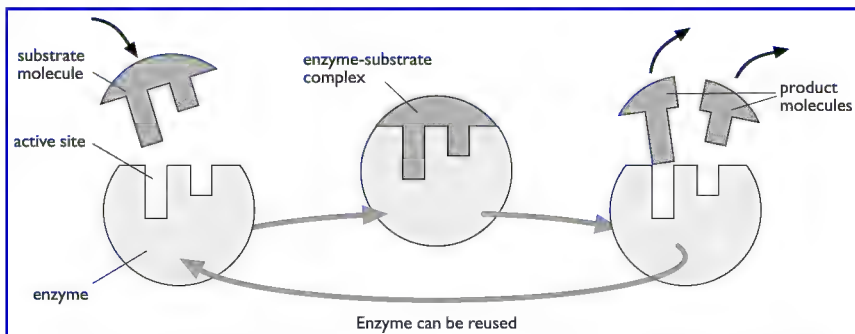
to allow the substrate molecules to interact to form the products. Once the products are formed, they are released from the active site and the enzyme is free to repeat the process

The formation of the enzyme-substrate complex provides an alternative route of lower **activation energy** which is the energy needed to start a reaction. In the laboratory, it is common for reacting substances (substrates) to be heated in order to make the reaction occur more quickly. The heat energy causes the molecules to move about more rapidly (i.e. it gives them more kinetic energy) so that they collide more frequently, forming the product. In other words heat is used to overcome the activation energy. Living cells operate at a constant relatively low temperature so therefore they rely on enzyme catalysts to overcome the activation energy.



The active site matches the substrate, so different shaped substrate molecules require different shaped active sites. Most biological reactions therefore involve different, **specific** enzymes. This is possible because proteins which make up enzymes can be made in an infinite variety of shapes as a result of the nature and sequence of the amino acids and their R group (tertiary and quaternary structures).

This model of enzyme action is referred to as the **lock and key model**, but it is known that the shape of the active site may change as the substrate makes contact with it, adjusting to make a close fit, rather like a soft glove around a hand, a mode of action called **induced fit**.



## FACTORS which AFFECT ENZYME ACTIVITY

### pH

This is a measure of  $H^+$  ion concentration, which is a measure of acidity and alkalinity. A pH of 7 is neutral, less than 7 is acid, and more than 7 is alkaline. Small changes in pH can affect the association process between enzyme and substrate which happens at the active site. The attraction between substrate and enzyme is often the result of small electric charges at the active site, and these are disrupted by changes in  $H^+$  ion concentration. Extremes of pH, i.e. very acid or alkaline conditions, cause permanent denaturation. Enzymes have an optimum pH for efficient functioning. Usually this is around pH7, the normal pH of cells. Notable exceptions are the enzyme pepsin, which is found in the stomach and works best in highly acidic conditions in the range pH 1-2, and the enzyme trypsin which is found in the duodenum and has an optimum pH of 9.

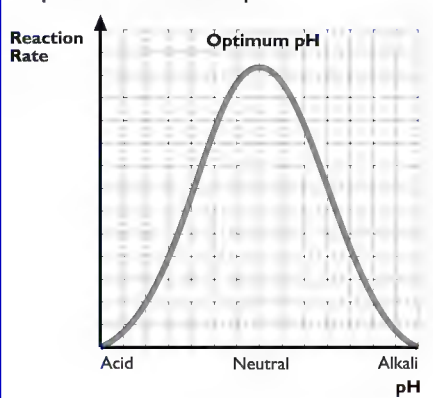
### Temperature

Temperature affects the rate of all chemical reactions. As the temperature increases, so does the kinetic energy of the reacting molecules. More enzyme/substrate complexes are formed as the reactants collide more frequently, and the reaction rate rises exponentially, doubling for every ten degree rise in temperature. However, enzymes, like all proteins, suffer irreversible alterations in molecular shape above certain temperatures as a result of the breaking of chemical bonds within the molecule, so that in enzyme-catalysed reactions, there is an **optimum** temperature above which the reaction rate drops sharply. For an enzyme, any change in the shape of the active site means a loss of function, the enzyme is said to be **denatured**. For most enzymes, the optimum temperature is around  $40^{\circ}C$ , but there are extreme exceptions. For example, some bacteria living in hot springs have enzymes which function at temperatures above  $85^{\circ}C$ , whilst the ice fish of the Antarctic possess enzymes which operate at  $-2^{\circ}C$ .

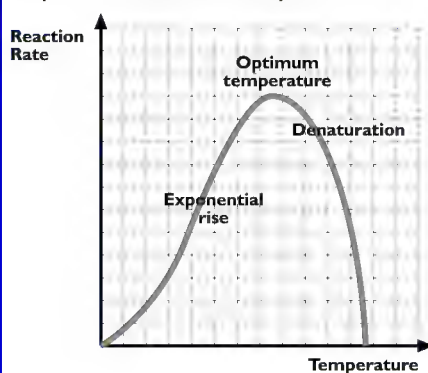
#### ◆ CHECKPOINT SUMMARY

- ◆ All enzymes are protein in nature, and fall into the group of 'globular' proteins with a complex 3D structure.
- ◆ Enzymes are catalysts which speed up the rate of reaction of much larger amounts of reactants without themselves being used up in the process.
- ◆ Unique amongst catalysts they are denatured by extreme conditions of pH and temperature.
- ◆ Their activity depends upon their complex 3D shape which creates an active site which combines with the substrate to form an enzyme/substrate complex which lowers the activation energy of reactants.
- ◆ Their complex 3D shape also accounts for enzyme specificity as the active site has a shape complementary to the shape of the substrate.
- ◆ Disruption of the 3D shape accounts for denaturation.
- ◆ pH has an effect on the 3D shape of enzymes and particularly the active site which has an electric charge, extremes of pH permanently disrupt the active site and thus denature the enzyme.
- ◆ Similar effects are seen with temperature, except low temperatures do not denature enzymes. The rate of enzyme catalysed reactions, like all chemical reactions, are reduced with low temperatures.
- ◆ Optimum conditions of pH and temperature vary with the particular enzyme, which reflects the conditions in which the cell exists.
- ◆ The relative amounts of enzyme and substrate affects the rate of reaction as it affects the formation of the enzyme substrate complex. Only one can be rate regulating or limiting at any one time.

Graph to show the effect of pH

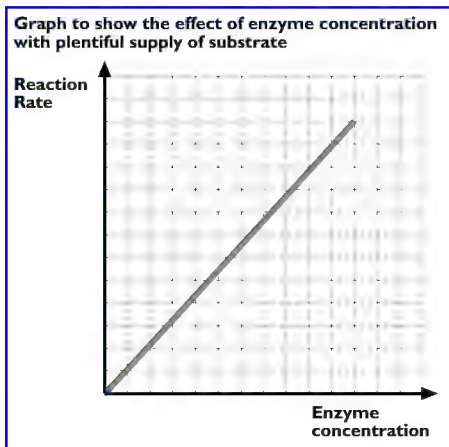


Graph to show the effect of temperature



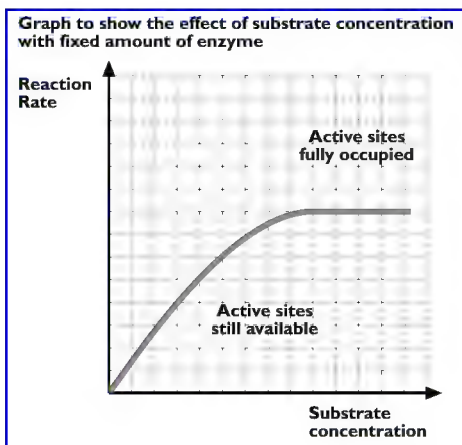
## Enzyme Concentration

Enzyme concentration exerts a direct effect on the rate of the reaction. As long as there is a plentiful supply of substrate, any increase in the number of enzyme molecules will result in a proportional increase in the number of enzyme-substrate complexes and therefore an increase in the rate of reaction.



## Substrate concentration

Substrate concentration has a similar effect. At low substrate concentrations, not all the active sites will be occupied, so the rate of the reaction depends upon the concentration of substrate alone. As the concentration of substrate increases, so all of the available active sites will become filled. The upper limit is determined by the amount of enzyme molecules available



## Learning Objective (LO)

### The TIME COURSE of ENZYME-CATALYSED REACTION

The time course or rate of an enzyme catalysed reaction can be followed by measuring the rate of formation of products e.g. the formation of oxygen by the action of catalase on hydrogen peroxide:



The formation of oxygen can be measured simply by estimating the amount of effervescence (bubbling).

Alternatively the rate of disappearance of the substrate could be measured e.g. the disappearance of starch as a result of the action of amylase:



The disappearance of starch is measured by the iodine in potassium iodide solution test in which the presence of starch is indicated by a blue/black colouration. The longer the experiment proceeds the less strong is the reaction of the sample, until such time that no colour change with iodine solution is obtained (the achromic point).

- ▼ Rates of disappearance of substrate are proportional to the rate of reaction.
- ▼ Rates of formation of end-product(s) are proportional to the rate of reaction.

## Learning Objective (LO)

### ENZYME INHIBITORS

Enzyme inhibitors are substances which interfere with the active site of the enzyme. They do this either directly by blocking it, or indirectly by attaching to another part of the enzyme and altering its molecular shape so that the enzyme-substrate complex can not be formed.

#### Competitive inhibitors

These are substances which have a molecular structure resembling that of the substrate. They attach themselves to the active sites forming inhibitor/enzyme complexes and cause the reaction to slow down or stop altogether. The effect of competitive inhibitors depends upon the relative concentrations of the substrate and inhibitor, and also the relative stability of the enzyme/substrate and inhibitor/enzyme complexes. This type of inhibition is seen in the action of a group of antibiotics called sulphonamides, which compete for the active site of a key bacterial enzyme involved in synthesising an essential growth factor, not found in the cells of the host.

#### Non-competitive inhibitors

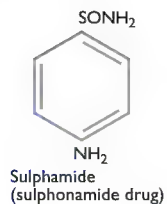
These are substances which bind onto the enzyme at a place other than the active site called an **allosteric site**, causing the enzyme to change shape sufficiently to stop enzyme-substrate complexes being formed. Non-competitive inhibitors are not similar to the substrate molecules and are not affected by the substrate concentration. The ions of some heavy metals such as arsenic and cyanide may bind onto allosteric sites and act as poisons, stopping important enzyme controlled reactions. Some enzyme molecules possess an allosteric site which must be occupied by an **activator** substance to give the enzyme its correct working shape. Without the activator, the enzyme will not work.

Inhibitors and activators are important in regulating the activity of enzymes.

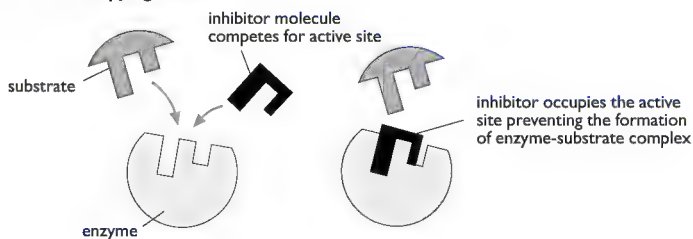
#### Substrate molecule



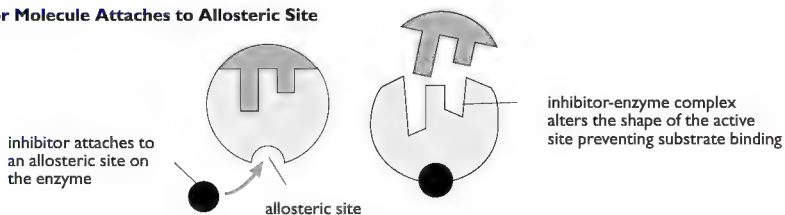
#### Competitive inhibitor



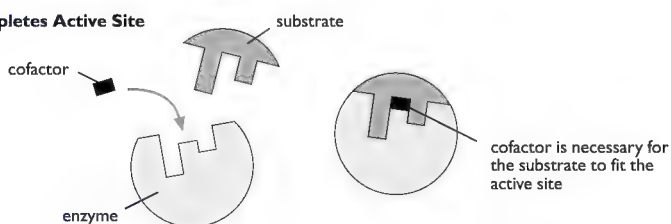
### Inhibitor Molecule Occupying Active Site



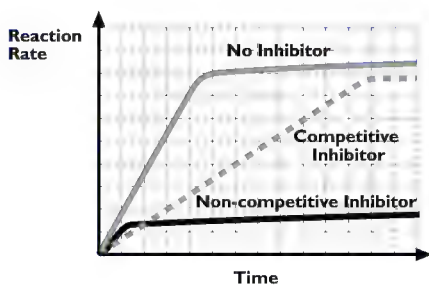
### Inhibitor Molecule Attaches to Allosteric Site



### Cofactor Completes Active Site



### Graph to show effect of inhibition



### ◆ CHECKPOINT SUMMARY

- ◆ Irreversible enzyme inhibitors are also referred to as poisons or toxins.
- ◆ Reversible inhibitors in contrast are not permanently damaging to enzymes, but typically act as regulators in cell metabolism.
- ◆ Competitive inhibitors have a molecular structure resembling that of the normal substrate to which the enzyme binds, and compete for the active site.
- ◆ The more molecules of competitive inhibitor there are, the more successfully they compete for the active site, and vice versa.
- ◆ Non-competitive inhibitors bind to the enzyme at a site away from the active site at a location known as the allosteric site.
- ◆ Combination at the allosteric site results in a change of shape of the enzyme molecule and active site, preventing the formation of enzyme-substrate complexes.



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## 1.4

# Cell Membranes and Transport

### Content

- ▼ The fluid mosaic model of membrane structure
- ▼ The movement of substances into and out of cells

Candidates should be able to:

- Describe and explain the fluid mosaic model of membrane structure, including an outline of the roles of phospholipids, cholesterol, glycolipids, proteins and glycoproteins.
- outline the roles of membranes within and at the surface of cells.
- describe and explain the processes of osmosis, passive diffusion, facilitated diffusion, active transport, endocytosis and exocytosis.
- describe the features of the gaseous exchange surface of the mammalian lung.
- describe the features of root hairs (including carrier molecules in membranes which enable the uptake of ions by active transport).

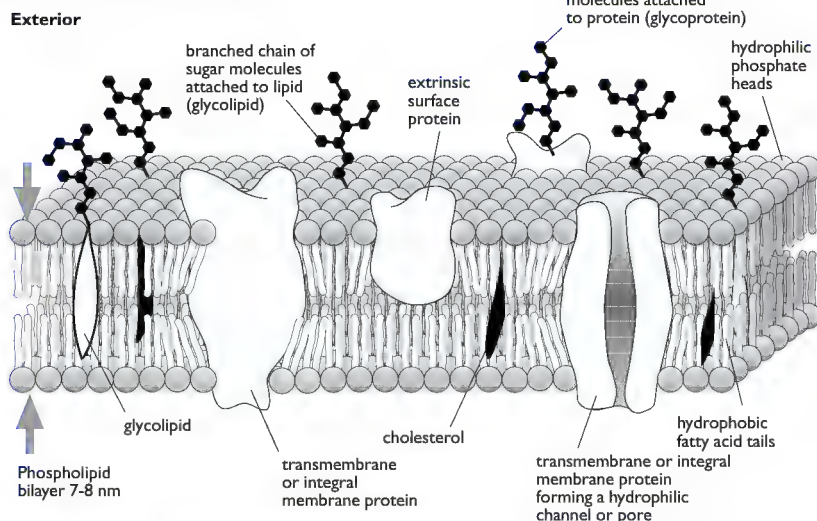
### MEMBRANE STRUCTURE the FLUID MOSAIC MODEL

The cell surface membrane (**plasmalemma**) and the membranes which enclose the cell organelles and make up the extensive system of interrelated channels and vesicles within the cell share the same structure. Membranes are constructed from lipid, protein and carbohydrate components. The structure is based on a bilayer of phospholipid molecules, strengthened by cholesterol. Phospholipids adopt this bilayer structure automatically in fluid surroundings because the fatty acid 'tails' of the molecules are water repelling (hydrophobic) whilst the phosphate/alcohol 'heads' are water attracting (hydrophilic).

Proteins of various sizes and shapes are located on and in the bilayer. Some are bonded to the hydrophilic head region and do not penetrate the interior of the membrane (**extrinsic proteins**), others, have one end buried within the fatty layer and one end sticking outside of the cell membrane (**intrinsic proteins**). A third kind, (**transmembrane proteins**), pass all the way through the membrane to create special channels. The carbohydrate component of cell membranes consists of short polysaccharide chains joined to membrane proteins or fats forming **glycoproteins** and **glycolipids** respectively, which project outside the cell membrane.

Individual molecules of phospholipid and protein in the membrane have a degree of **mobility** within the membrane. This fluidity, coupled with the bubbled appearance of the proteins on the surface of membranes gave rise to the the term '**fluid mosaic model**' when the structure was first proposed. Cholesterol stabilises membranes by limiting the movement of phospholipid molecules within the membrane.

## Fluid mosaic model of cell surface membrane



## Learning Outcome (b)

### OUTLINE of the ROLES of MEMBRANES within and at the SURFACE OF CELLS.

**Receiving Messages** Cells have the ability to sense and respond to the presence of a great variety of molecules. This ability is due to proteins in the surface membrane which act as **receptors**. Hormones such as insulin and adrenalin, and many drugs and toxins lock onto recognition sites on receptor proteins triggering changes in the cell's behaviour.

**Recognition of foreign cells and molecules** Glycoproteins and glycolipids have a very important role in personalising a cell's identity. They are orientated in the membrane bilayer with the chain of sugar molecules to the outside. The possibility for variation in the structure and different combinations of these chains gives an endless range of different surface patterns, and forms the basis of a recognition system. Each individual has his or her own cell surface 'print'. Self recognises self, and immune systems are mobilised when 'non-self' substances are encountered. The glycoproteins and glycolipids of the cell membrane are responsible for an individual's tissue type, a well known example of which is the blood groups.

**Surface for the attachment** of organelles (ribosomes), enzyme complexes (on cristae of inner membrane of mitochondria), and other cells.

**Partially permeable barrier** to the passage of substances into and out of the cell, for example water and fat soluble substances pass through more easily than sucrose. The different rates of passage of electrically charged ions generate membrane potentials which in turn influence the further uptake of charged ions, and are also involved in cell sensitivity, particularly in nerve cells.

### ◆ CHECKPOINT SUMMARY

- ◆ All cell membranes are thought to share the same structure except the inner membrane of mitochondria.
- ◆ The common structure is based on a lipid bilayer formed from phospholipids aligning themselves with their hydrophobic poles next to each other within the membrane, and hydrophilic poles facing outwards.
- ◆ This fluid arrangement is stabilised by the presence of another lipid, cholesterol.
- ◆ Various proteins are embedded within this lipid bilayer.
- ◆ Extrinsic proteins are found on the surface of the membrane.
- ◆ Intrinsic proteins have one end embedded in the lipid bilayer and the other protruding out of the external surface of the membrane.
- ◆ Transmembrane proteins span the lipid bilayer and create aqueous channels or pores through which water soluble substances can pass by diffusion.
- ◆ Short polysaccharide chains attached to proteins (glycoproteins) and to fats (glycolipids) protrude from the external surface and act as cell recognition sites (receptors or antigens).
- ◆ The patchwork arrangement of all these types of molecules in the lipid bilayer is the origin of the description 'mosaic'.

## TRANSPORT ACROSS CELL MEMBRANES

The transport of respiratory gases, nutrients and metabolic waste products occurs through the membrane, either directly through the bilayer, or via channels or 'pores' created by transmembrane proteins. In some cases the substances move down a concentration gradient (ie from high concentration to lower concentration) which is known as **passive transport**. In others, substances are moved against the concentration gradient (ie from low concentration to higher concentration) in a process requiring energy in the form of ATP, which is known as **active transport**.

### Passive diffusion

Molecules and ions may move passively by diffusion, which is defined as the overall (net) movement of substances from regions of their higher concentration (higher chemical potential) to regions of their lower concentration (lower chemical potential) until equilibrium is reached. The movement of the particles of substances in diffusion is random in all directions, as a result of their inherent kinetic energy. If there are more in one area than another, the net effect is for the particles to distribute themselves equally throughout that particular space, ie the concentration gradient evens out until at equilibrium there are an equal number of particles moving in all directions. The speed of these diffusing particles is only increased by an increase in temperature, which increases their kinetic energy. In addition to the effect of temperature on diffusion, the amount of a substance that diffuses in a given time (rate of diffusion) is dependent upon the difference in its concentration in two separated regions (the **concentration gradient**), the surface area of the separating boundary or exchange surface, and the distance separating them. that is the thickness of the exchange surface; a relationship expressed in the following equation known as **Fick's law**.

$$\text{Rate of diffusion} = \frac{\text{difference in concentration} \times \text{surface area}}{\text{thickness of the exchange surface}}$$

This gives a rough guide to the rate at which a substance such as oxygen diffuses from the air in an air sac (alveolus) in the lung into the blood in a lung capillary. In principle; the greater the surface area, the greater the concentration difference, and the thinner the separating layers, the greater the rate of diffusion.

The most important factor affecting diffusion across cell membranes, however, is the chemical nature of the substance being transported. Diffusion across the bilayer depends principally upon the solubility of the substance in fat. You will remember that the phospholipid bilayer is strongly hydrophobic. Polar molecules such as glucose, some amino acids, and inorganic ions pass through very slowly or not at all, whilst non polar molecules such as calciferol (vitamin D) move across with ease. It is interesting to note that the first anaesthetics (chloroform and ether) were fat solvents that disrupted membrane structure and function especially in nerve cells.

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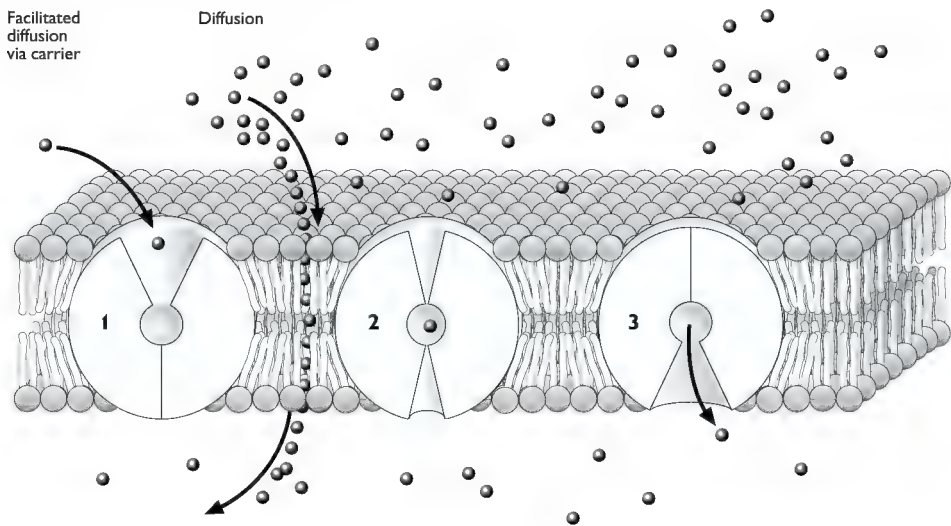
## Facilitated diffusion

The transport of polar molecules e.g. glucose, some amino acids, and inorganic ions, across cell membranes, occurs through hydrophilic channels formed by transmembrane proteins, in a process called facilitated diffusion. Polar molecules also become temporarily attached to special binding sites on transmembrane proteins called **carriers**. These are rather like enzymes in that they are shape specific and accelerate a process which is already 'downhill' in terms of energy. All that is needed is a concentration gradient. The attachment of a molecule to the binding site alters the overall shape of the carrier in such a way as to deposit the molecule on the other side of the membrane along their normal concentration gradients.

As has been seen, the transport of inorganic ions such as sodium ( $\text{Na}^+$ ), potassium ( $\text{K}^+$ ), calcium ( $\text{Ca}^{++}$ ) and chloride ( $\text{Cl}^-$ ) across cell membranes depends upon transmembrane proteins.

Some transmembrane proteins form selective **ion channels** through which the facilitated diffusion of ions occurs down their concentration gradients. These ion channels cannot be coupled to an energy source, and cannot be involved in active transport across the membrane.

### Diagram to show diffusion and facilitated diffusion



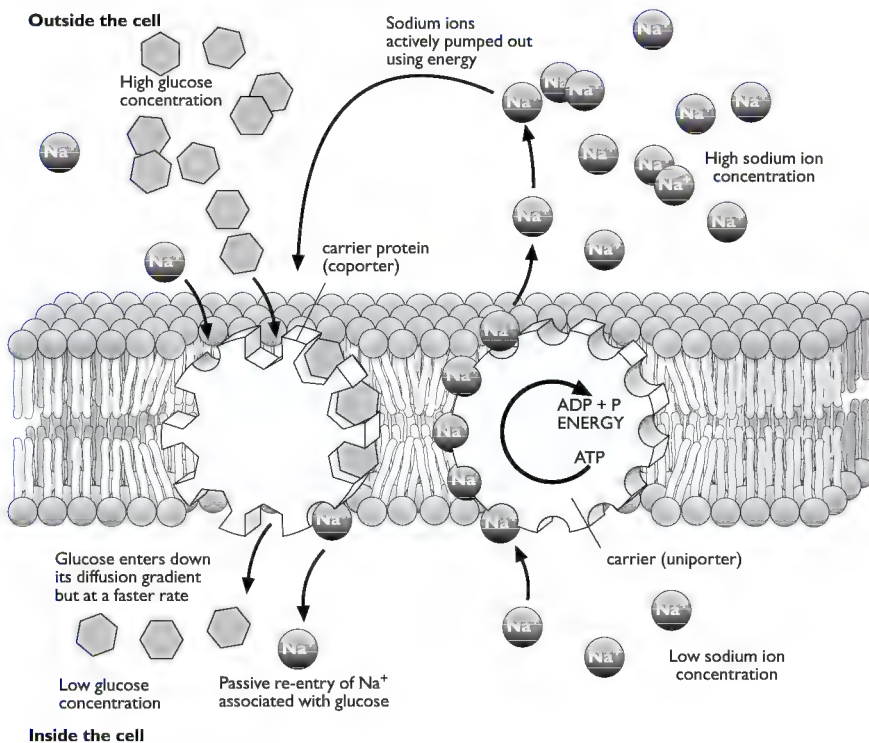
## Active transport

Some transmembrane proteins act as active **ion pumps**, which use energy from respiration, to move ions against their concentration gradients. The ion channels can open and close like 'gates', and the activity of the ion 'pumps' can be varied. In these ways, the membrane can be made selectively permeable to certain ions at certain times.

As a result of the distribution of ions on either side of the membrane **transmembrane potentials** are created, in which there is an overall difference in electric charge between the inside and the outside of the membrane. In normal conditions, the inside of the cell membrane is negatively charged relative to the outside, and this will assist the uptake of positively charged ions (cations) and oppose the uptake of negatively charged ions (anions). Thus the movement of ions across membranes is influenced by both electrical and chemical gradients i.e. **electro-chemical gradients** (these have particular importance for the function of nerve and muscle cells).

Some of these transmembrane protein carriers carry two substances at once in a **coupled mechanism**. A common example is the sodium/potassium pump ( $\text{Na}^+/\text{K}^+$  pump), in which the active pumping of sodium out of a cell is coupled with the pumping-in of potassium, both against their diffusion gradients (for every two sodium ions pumped out, three potassium ions are pumped in, resulting in high potassium and low sodium levels within the cell). Another example is where the sodium pump is linked to the uptake of glucose. The sodium ions are pumped actively out of the cell and diffuse back into the cell via a carrier associated with glucose. In this case the glucose is moving passively down its concentration gradient, but at a faster rate as a result of its association with the re-entry of sodium which is kept at a high rate by its being continually pumped out of the cell.

**Diagram to show active transport (ion pumps)**



## Osmosis - movement of water across cell membranes

As has been seen, cell membranes are **partially permeable**, allowing the passage of substances at different rates. Generally cell membranes are more permeable to water than to many solutes.

Water moves according to the same principles of diffusion, but it is not usual to refer to high and low 'concentrations' of water - the term 'concentration' being traditionally associated with any solutes dissolved **in** water in a solution. Therefore the preferred term is the chemical potential of water or **water potential**.

Water always moves (diffuses) from a region of higher water potential to one of lower water potential. You could think of water potential as the **tendency for water molecules to move** i.e. diffuse. The higher the water potential the more easily will the water molecules move, and the lower the water potential the less easily will the water molecules move.

At standard pressure and temperature, pure water has the highest water potential. If substances are dissolved in solution then the water potential is decreased because the solutes associate with water to a greater or lesser extent and reduce the ease with which the water molecules can move. Therefore any solution has a lower water potential than pure water, and a more concentrated solution has a lower water potential than a less concentrated solution.

Water potential of a fluid can be described as the tendency of water to move into it from pure water. If the fluid **is** pure water, there is no movement, so the **water potential of pure water is zero**.

The water potential of any **solution is less than pure water and is therefore negative**. The more negative the water potential the greater the tendency of water to move into that system. Water potential is measured in units of pressure (kPa).

Where a solution is separated by a partially permeable membrane from pure water or a less concentrated solution, water will diffuse into the more concentrated solution until equilibrium is reached. The special case of the diffusion of water across a partially permeable membrane is known as **osmosis**.

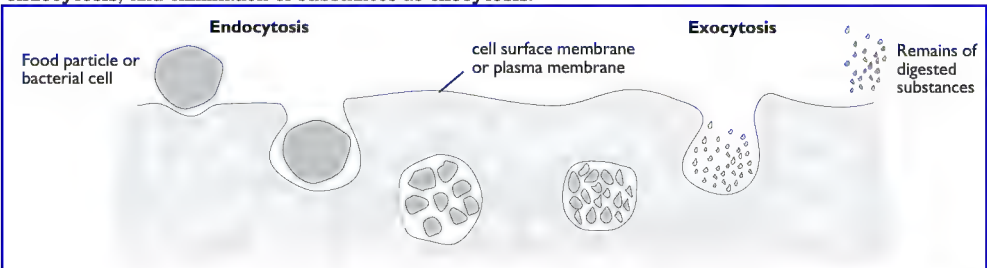
The water potential of soil may be close to 0, whilst that of the cells of the root may be -100kPa, that of the leaves -1,200kPa and that of the air -30,000kPa. This helps to explain why water moves from soil to roots, from roots up the stem to leaves, and from leaves to the air.

## Bulk transport of liquids and solids

This is achieved by membranes pinching off small bubble-like vesicles which can fuse with other membranes to transfer their contents. Uptake of substances into the cell in this way is known as **endocytosis**, and elimination of substances as **exocytosis**.

### CHECKPOINT SUMMARY

- ◆ The cell surface membrane defines the limits of the cell.
- ◆ It acts as a partially permeable membrane regulating the transport of substances across the membrane.
- ◆ Internal membrane systems provide a surface for attachment of organelles and enzymes, and compartmentalise specialised functions within the cell.
- ◆ Passive diffusion occurs across membranes down diffusion gradients from high concentration to low concentration. Fat soluble substances diffuse faster than non-fat soluble substances which must pass through the aqueous pores.
- ◆ Osmosis is the special case of the diffusion of water from regions of higher water potential to regions of lower water potential across a partially permeable membrane which is more permeable to water than to dissolved solutes. (If the membrane was fully permeable the solutes would diffuse down their diffusion gradient and the water would not move.)
- ◆ At standard room temperature and pressure pure water has the highest water potential which is given the value of zero. Solutions have a water potential of less than zero (negative).
- ◆ Facilitated diffusion occurs via specialised carriers in the membranes which reduce the resistance to the diffusion of these substances.
- ◆ Active transport involves energy, in the form of ATP from respiration, to pump ions across the cell surface membrane via carriers, against their diffusion gradient.
- ◆ Mass or bulk transport of fluids into and out of the cell is achieved by vacuoles fusing with, or being pinched off from, the cell surface membrane respectively.





## FEATURES of the GASEOUS EXCHANGE SURFACE of the MAMMALIAN LUNG

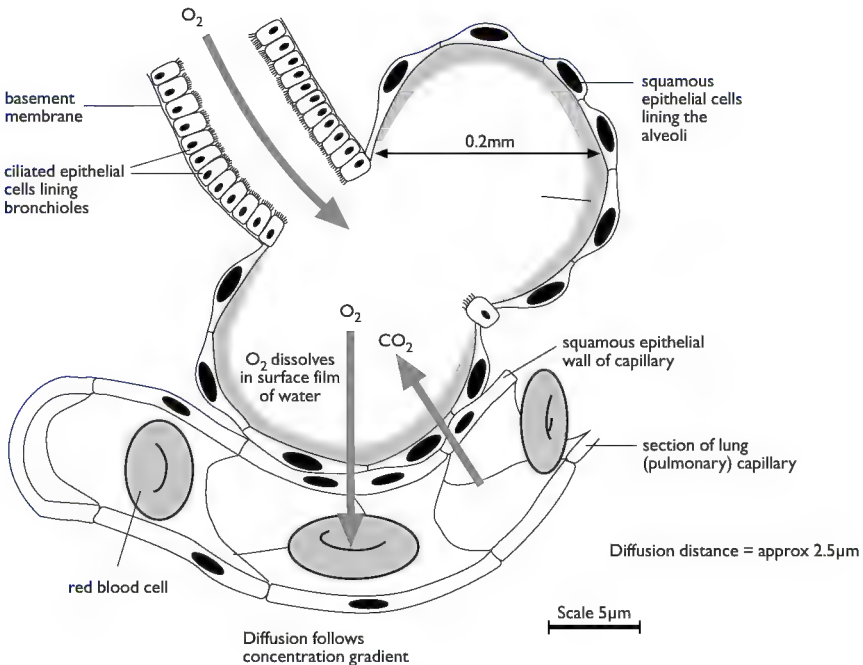
The gaseous exchange surface of the mammalian lung is found in the air sacs (alveoli). The 300 million alveoli of the lungs have a huge surface area of about  $70 \text{ m}^2$ , and their walls are made up of very thin flat lining cells (squamous epithelium). The capillaries of the pulmonary circulation are sandwiched between the thin walls of adjacent alveoli, causing the alveoli surfaces to be ridged and corrugated, which further increases their surface area. These capillary networks are the most dense in the body. The capillaries also have very thin walls, so that the total thickness of cells between the air and blood is kept to a minimum.

Being a thin permeable membrane with gases on one side and body fluids on the other there is an inevitable loss of water into the alveoli from the blood in the capillaries. This fluid forms a surface film over the alveoli and slows the uptake of oxygen. This slowing is due to the increase in diffusion distance between the capillaries and the air in the alveoli, plus the fact that the diffusion of oxygen in solution is much slower than it is as a gas. The effect on the release of carbon dioxide is not so great due to the much greater solubility of carbon dioxide than oxygen in water.

### CHECKPOINT SUMMARY

- ◆ The gaseous exchange surface of the mammalian lung is the squamous epithelium lining the alveoli.
- ◆ Squamous epithelium is made up of tightly interlocking thin flattened cells with a large surface area to volume ratio.
- ◆ The total surface area of the lungs is large as a result of being divided up into about 300 million alveoli.
- ◆ Dense capillary networks sandwiched between the walls of the alveoli make the walls of the alveoli ridged, further increasing their surface area.

### Alveolus Sac and Capillary Cross Section

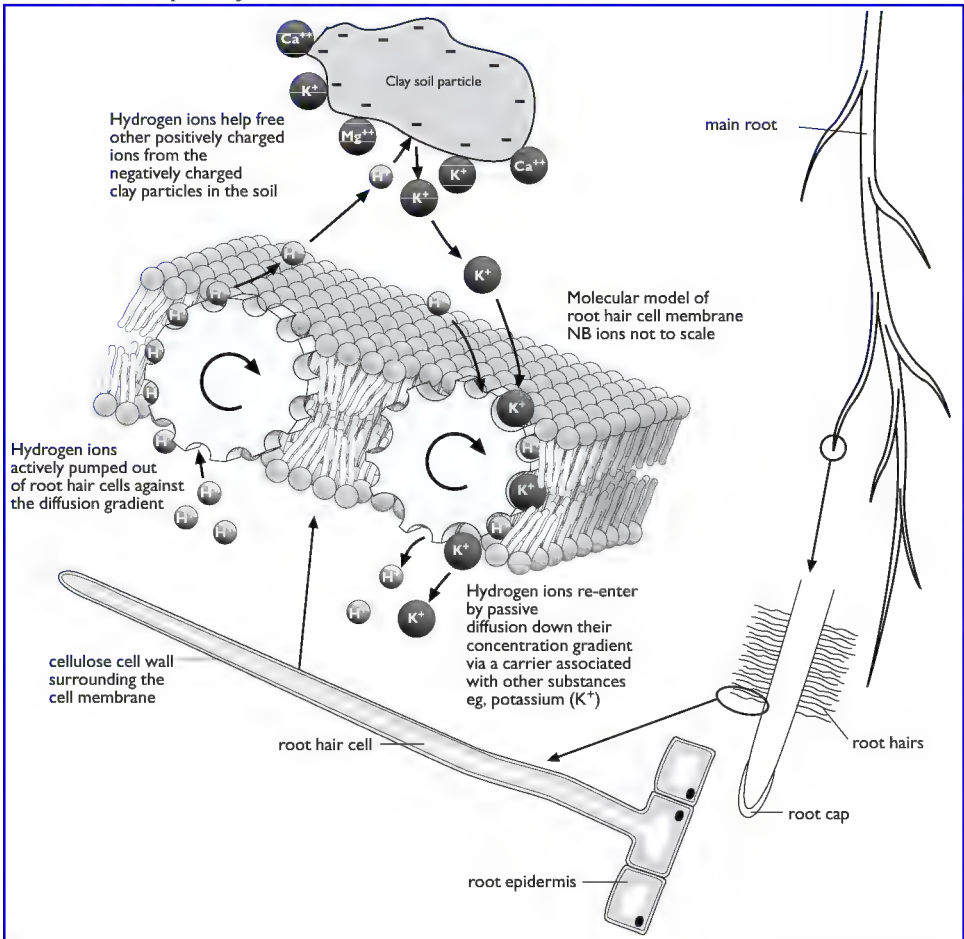


## FEATURES of PLANT ROOT HAIRS as CELLS SPECIALISED for the UPTAKE of SUBSTANCES

A plant root hair cell is a single cell with a long fine extension which greatly increases the surface area for the uptake of water and dissolved solutes (inorganic ions or 'minerals') from the soil solution. Large numbers of root hairs are found just behind the tips of all the roots, providing a large total surface area for absorption. Uptake of inorganic ions by the root hairs is both passive by diffusion and active. Root hair respiration produces ATP which is used to supply energy for active uptake of inorganic ions from the soil solution. Respiration also releases hydrogen ions (protons), which are actively pumped out of the root hair cells, setting up a transmembrane potential and creating both the directional stimulus and energy for the inward flow of nutrient ions. The exported hydrogen ions also release other positively charged ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{++}$ ) from the negatively charged clay particles of the soil and make them more available for active uptake by the roots.

### ◆ CHECKPOINT SUMMARY

- ◆ Root hairs consist of one cell with an elongated 'hair-like' protrusion, giving each one a large surface area to volume ratio.
- ◆ Large numbers of root hair cells just behind the growing tips of roots present a large total surface area for the uptake of water and solutes from the soil solution.
- ◆ Carrier molecules in their membranes enable the active uptake of ions (especially positively charged cations) from the soil solution.
- ◆ Cations are held by the electronegative clay particles of the soil, and are liberated by exchange with hydrogen ions from the cellular respiration of the root hair cells.





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## 1.5

# Genetic control of protein structure and function

### Content

- ▼ The structure and replication of DNA
- ▼ The roles of DNA and RNA in protein synthesis
- ▼ The principles of gene manipulation

Candidates should be able to:

- describe the structures of DNA and RNA, and explain the importance of base pairing and hydrogen bonding.
- explain how DNA replicates semi-conservatively during interphase, and interpret experimental evidence for this process. (Reference should be made to DNA polymerase.)
- state that a gene is a sequence of nucleotides as part of a DNA molecule, which codes for a polypeptide.
- describe the way in which the nucleotide sequence codes for the amino acid sequence in a polypeptide.
- describe how the information on DNA is used to construct polypeptides, including the role of messenger RNA, transfer RNA and the ribosomes.
- explain that, as enzymes are proteins, their synthesis is controlled by DNA.
- outline the general principles of gene manipulation by biotechnology, with reference to the synthesis of human insulin by bacteria and human factor VIII.

### STRUCTURE of DNA and RNA

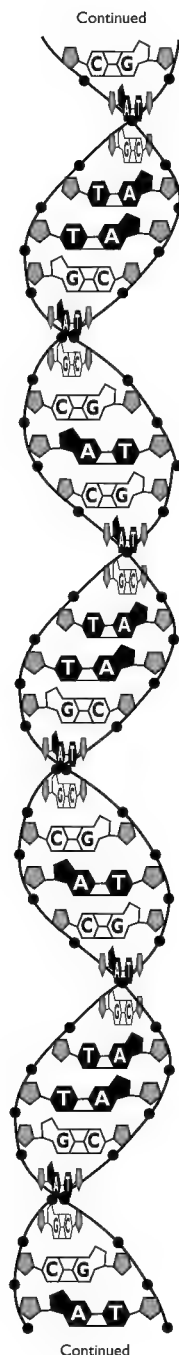
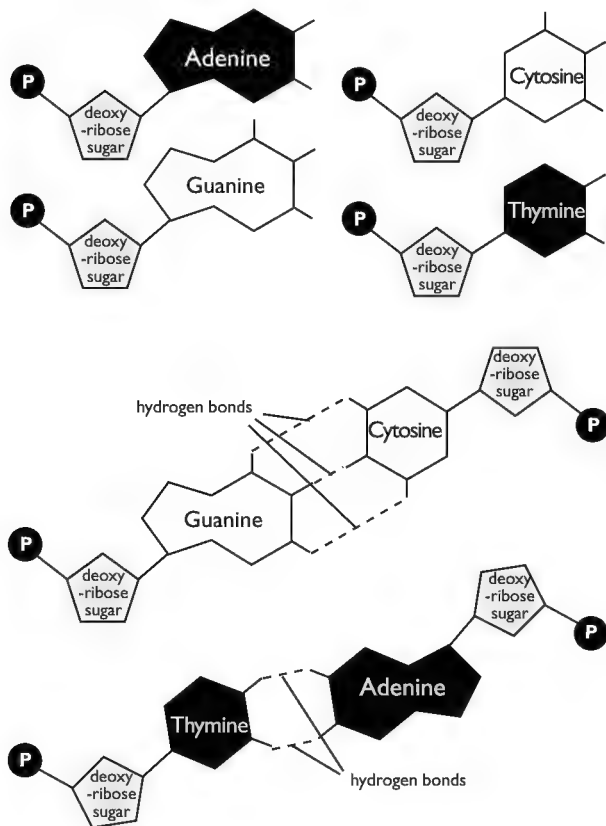
**DNA (deoxyribonucleic acid)**, is so named because it is an acid and it is found in the nucleus. It is a polymer made up of repeating sub-units, in this case, **nucleotides** linking up to form a **polynucleotide**. What makes DNA so important and so unique is that it contains within its structure the **genetic code**, and it can produce copies of itself (replicate).

The nucleus of cells contains mostly DNA and protein. For many years it was thought that protein was the hereditary material but when it became possible to extract and measure the quantity of DNA, it was found that the DNA content doubled in cells just prior to division. It was also found that, in the formation of gametes (sperms and eggs), the amount of DNA halved. Both pieces of evidence underline its central role in inheritance. Now it has become possible to analyse the molecular structure of DNA, to unravel the chemical code it contains, and to transfer pieces of this code between one organism and another in the process known as genetic engineering.

DNA is a polynucleotide made up of repeating nucleotide units. A nucleotide consists of three main parts: a **pentose (5 carbon) sugar** joined to a **phosphate group** and a nitrogen-containing ring structure called an **organic base**. There are four different types of nucleotide in DNA each with a different organic base. The bases are **adenine** (A) and **guanine** (G) which belong to a group of chemicals called **purines**, and **cytosine** (C) and **thymine** (T) which belong to group called **pyrimidines**. Chains of nucleotides link up by **condensation** reactions, with the sugar and phosphate molecules forming the 'spine' of each strand of the molecule, with the bases to one side.

DNA consists of two such chains or **strands** linked by **hydrogen bonds** which form between pairs of bases. As the hydrogen bonds form, so the two strands of the DNA molecule twist into the spiral structure known as the **double helix**. Hydrogen bonds form only between specific pairs, namely A with T and C with G. The strands are therefore **complementary** to each other. The sequence along one strand determines the sequence of the other (complementary) strand. The understanding of the structure of the DNA double helix was one of the most significant breakthroughs in Biology.

### The Nucleotides of DNA



**RNA (Ribonucleic acid)**, like DNA, is a polymer made up of repeating nucleotides. It differs from DNA in the following three ways.

RNA is single stranded, not double stranded.

The pentose sugar in RNA is ribose, not deoxyribose (molecules of ribose contain an additional oxygen atom).

The pyrimidine base Thymine (T) is substituted in RNA by another pyrimidine base **Uracil (U)**

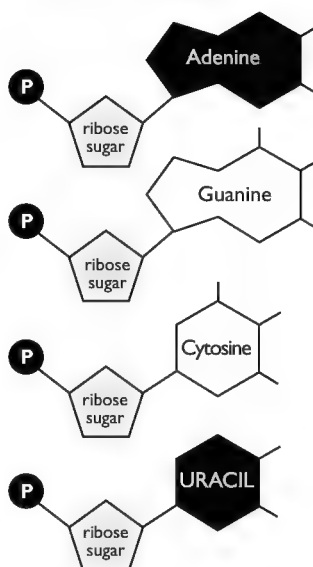
Living cells produce three different types of RNA, each designed to carry out a specific function in protein synthesis.

**Messenger RNA (mRNA)** consists of a single unfolded strand, between 75 and 3000 nucleotides long, produced in the nucleus as an exact copy of a selected section of the DNA code. The mRNA molecules travel out of the nucleus to the ribosomes where proteins are synthesised.

**Transfer RNA (tRNA)** is a shorter length of RNA, between 75 and 90 nucleotides long, twisted into a characteristic shape which allows one end to attach to a specific amino acid, and the other to expose a triplet of bases called the **anti-codon** which attaches to mRNA at the site of protein synthesis. tRNA molecules bring amino acids to their correct position on the mRNA as the proteins are being assembled. Each type of amino acid is carried by a different type of tRNA molecule with a specific anti-codon.

**Ribosomal RNA (rRNA)** consists of more than 1000 nucleotides and is found in ribosomes which are composed of an approximately equal mixture of proteins and rRNA. Ribosomal RNA is manufactured within the nucleolus.

#### The Nucleotides of RNA



### Learning Outcome (LO)

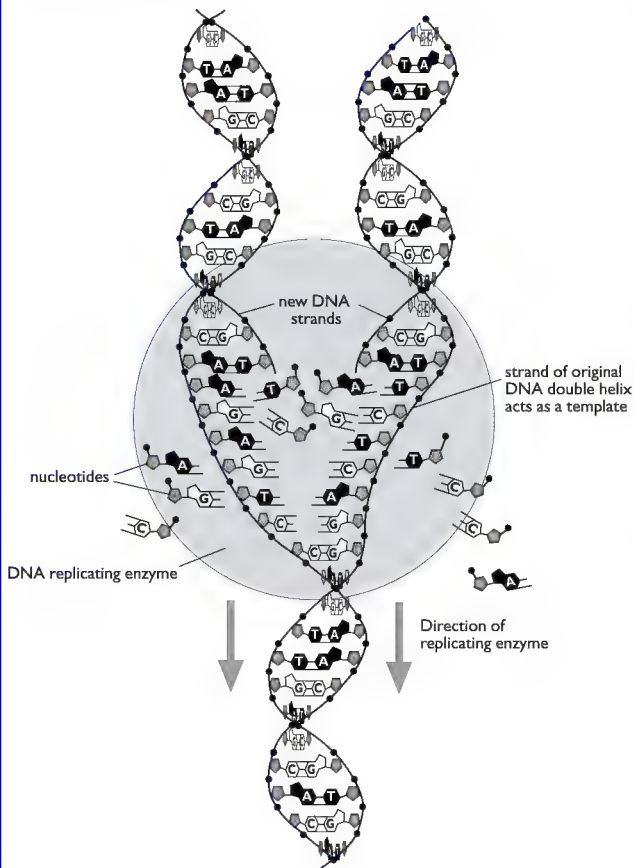
#### REPLICATION of DNA

In the process of **DNA replication** the original strands separate and each acts as a pattern (template) for the formation of another new strand. Each of the daughter DNA molecules retains (conserves) one of the original strands. For this reason, the process of replication is said to be **semi-conservative**. The process needs a supply of the four different nucleotides, energy in the form of ATP, and an enzyme called **DNA polymerase**, which is necessary to catalyse the condensation reactions by which free nucleotides form a copy of the template strand.

#### Experimental evidence

Experimental evidence for the semi-conservative mechanism of DNA replication includes experiments in which the mass of the DNA content of *E. coli*, grown on different nutrient media was determined and compared. One batch of microorganisms was cultured on a medium containing a 'heavy' isotope of nitrogen ( $^{15}\text{N}$ ), the DNA was extracted and compared with that of organisms cultured on a medium containing normal 'light' nitrogen ( $^{14}\text{N}$ ). The *E. coli* cells grown on 'heavy' nitrogen were then transferred to a new medium containing only light nitrogen and allowed to divide once to produce a new generation. The DNA of these daughter cells was found to be halfway between the 'heavy' and 'light' values, indicating that half the DNA was old and half was new (semi-conservative replication).

## Replication of DNA



### ◆ CHECKPOINT SUMMARY

- ◆ DNA and RNA are long chain polynucleotide molecules with repeating sub-units of nucleotides.
- ◆ Nucleotides consist of a 5 carbon (pentose) sugar; a phosphate base and an organic base.
- ◆ In DNA the sugar is deoxyribose and the organic base can be one of adenine, thymine, cytosine and guanine.
- ◆ In RNA the sugar is ribose and the organic base can be one of adenine, uracil, cytosine and guanine.
- ◆ The DNA molecule is a double stranded helix with the two strands held together by hydrogen bonds between complementary base pairs adenine-thymine and cytosine-guanine.
- ◆ RNA is a single stranded helix with base pairs of adenine-uracil and cytosine-guanine.
- ◆ There are three types of RNA messenger; transfer and ribosomal.
- ◆ DNA carries out semi-conservative replication in which each strand of the original molecule acts as a template for the construction of a new one, so that each new double stranded molecule of DNA consists of one original strand and a new complementary strand.

## Learning Outcome (LO 1)

### The GENETIC CODE

The DNA base sequence forms a four letter language which, as you have seen, can be copied every time a cell divides. This DNA base sequence determines the sequence of amino acids in a polypeptide chain (the primary structure of proteins). A sequence of nucleotides and their bases which codes for one polypeptide is known as a **gene**. Each gene codes for a different polypeptide chain. The primary structure of a polypeptide is the basis of the particular structural shape and characteristic of the final protein, e.g. enzymes, structural materials and membrane proteins. The base code determines the structure, functions and individuality of every organism.

Remember that up to twenty different types of amino acids may occur in a single protein. The DNA code has a four letter base language (A,G,C,T). A triplet of bases (sequence of three in a row) codes for each amino acid, for example 'CGC' codes for the amino acid alanine (Ala) whilst 'GCT' codes for arginine (Arg), so the code 'CGC-GCT-CGC' would be translated as 'Ala-Arg-Ala' in a polypeptide. Note that the code is non-overlapping, i.e. it must be read 'CGC-GCT-CGC', not 'CGC-GCG-CGC-GCT-CTC-' etc.

Sixty four different triplet codes (**codons**) are possible with this four letter base language, more than sufficient to code for the twenty different types of amino acids. In fact most amino acids are coded for by more than one codon. The process by which the code is used in protein synthesis, is described below.

## PROTEIN SYNTHESIS

Protein synthesis involves all three of the RNA types described above working in combination, and is achieved in two stages. As the DNA cannot leave the nucleus, first the code has to be read and copied (transcribed) into mRNA, in a process called **transcription**. The mRNA moves out of the nucleus and associates with the ribosomes, where the code (now copied in the mRNA) is used in the synthesis of a polypeptide in the process of **translation**.

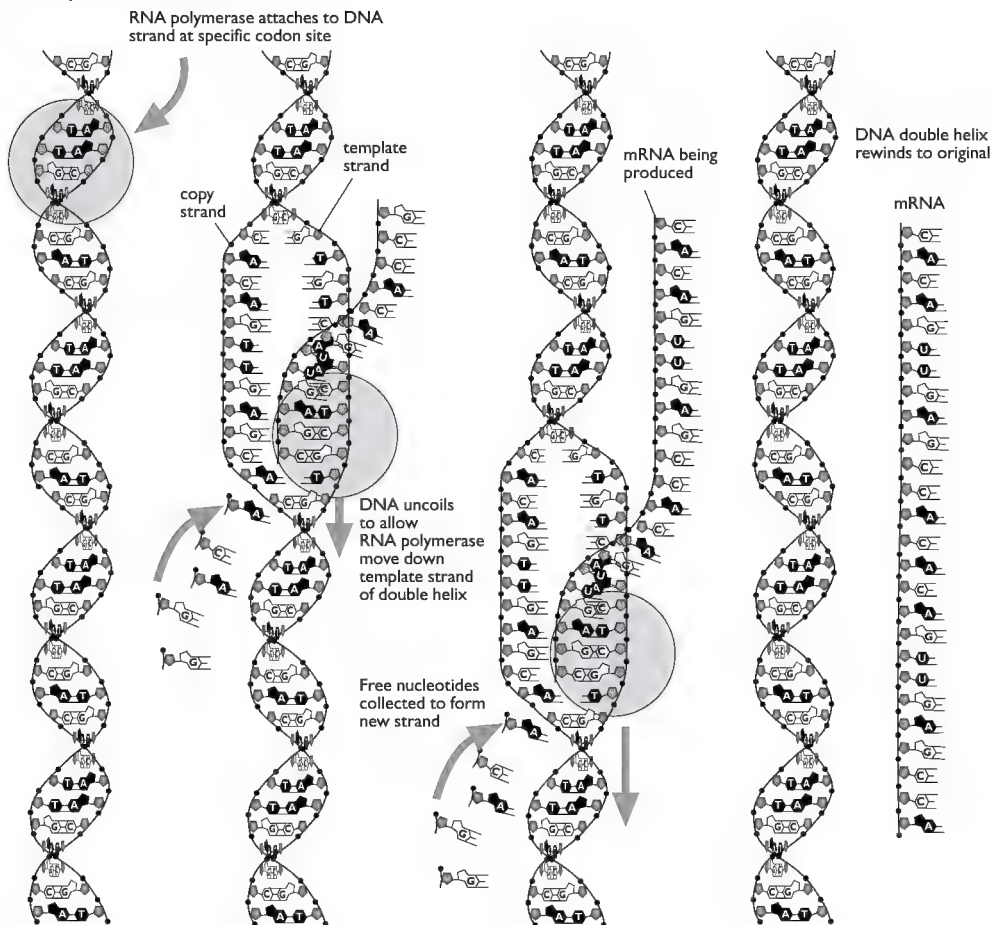
**Transcription** begins as an enzyme, **RNA polymerase**, attaches to the 'Start' codon of a gene. The DNA base sequence of this 'Start' codon is always 'TAC'. As RNA polymerase attaches to the DNA, the hydrogen bonds binding the two strands of the DNA double helix break apart to expose the sequence of triplet base codons on both strands. The enzyme then travels rapidly down the length of the gene like a zip fastener unzipping the DNA. As it does so, a molecule of mRNA is formed copying one of the DNA strands. Only one of the two DNA strands (the **template strand**) is copied into mRNA. The mRNA is therefore an exact replica (save that 'T' is substituted for 'U') of the other strand, which is consequently referred to as the **copy strand**. When the enzyme reaches the 'Stop' codon of the gene, transcription ends, the enzyme is free to start the process again, and mRNA is released from the nucleus to reach the ribosomes where the next stage occurs.

A complicating feature of the process of transcription in eukaryotic cells (cells with a nucleus) is that the length of DNA (the gene) to be copied into mRNA (the gene) has sections of 'junk code' which do not code for any of the required amino acids in a polypeptide chain. The 'junk' sequences are called **introns** (because they stay within the nucleus) and the parts to be transcribed and translated are called **exons**. The whole length is transcribed into mRNA, but before it is released from the nucleus, the introns are cut out with the assistance of enzymes, leaving a single, 'unpolluted', strand.

### ◆ CHECKPOINT SUMMARY

- ◆ The sequence of bases (and hence nucleotides) on one strand of the DNA molecule carries the genetic code for the synthesis of proteins and hence ultimately living cells.
- ◆ Three bases (a triplet codon) code for one amino acid.
- ◆ There are 64 possible combinations of any three from four bases, but only 20 amino acids to be coded for.
- ◆ Amino acids are coded for by more than one triplet codon and the code is said to be 'redundant' or 'degenerate'.
- ◆ A gene is a sequence of nucleotides of a DNA molecule which codes for a polypeptide.
- ◆ A gene for a polypeptide has a specific 'start' codon which thus sets the order of all the subsequent triplet codons
- ◆ Thus the code is non-overlapping i.e. a base can only be 'used' in one triplet codon.
- ◆ Only a fraction of the nuclear DNA contains genes coding for proteins, the rest consists of so-called 'junk' DNA the function of which is not understood.

## Transcription onto mRNA



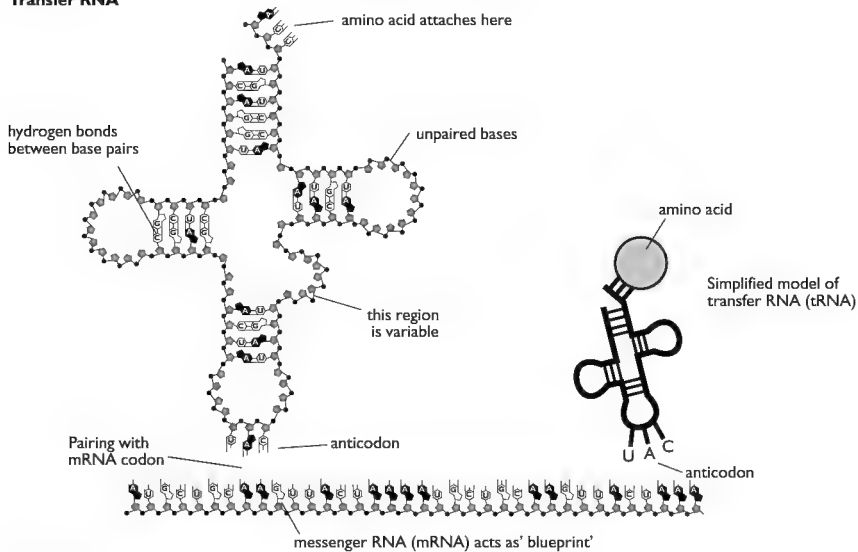
**Translation** occurs at ribosomes which are made up of two sub-units, one larger than the other, which come together only for the purpose of translating a length of mRNA. The mRNA binds to the small sub-unit at its 'Start' codon (AUG). It is then joined by the large sub-unit along with a molecule of tRNA which has the anti-codon 'UAC' and which carries the amino acid methionine. As the three different RNA types come together, the interface between the small and large sub-unit of the ribosome forms two binding sites allowing two triplet codons be lined up side by side. The process of translation can then proceed.

A second tRNA now occupies a position on the mRNA alongside the first and, as it does so, a peptide bond is formed between the two amino acids. The ribosome moves along the length of the mRNA, and once a tRNA molecule has delivered the appropriate amino acid it is released to repeat the process. New tRNA molecules with their amino acids come to occupy the ribosomal coding sites, and the polypeptide

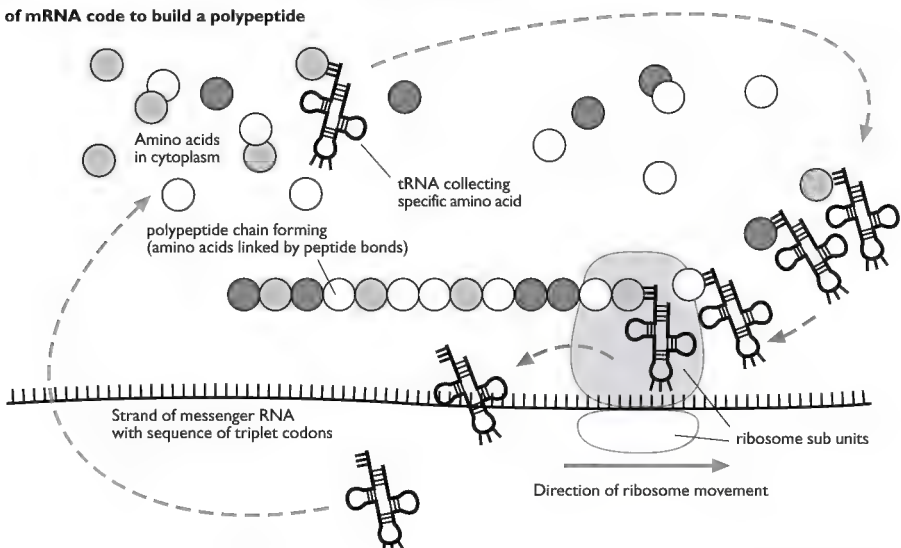
chain grows ever longer. When the ribosome reaches the 'Stop' codon (UAG) on the mRNA, it splits into its separate sub-units releasing the mRNA and the now complete polypeptide. A number of ribosomes move along the mRNA at the same time so that many polypeptide molecules are formed simultaneously. It is calculated that, in the average mammalian cell, more than a million new peptide bonds are being formed every second.

Generally mRNA molecules only have a short existence, sometimes just a few minutes, so that if continuous supplies of a particular protein are required the above processes must be repeated.

#### Transfer RNA



#### Translation of mRNA code to build a polypeptide





## DNA CONTROL of ENZYME SYNTHESIS

All cells of an organism will contain two copies of each gene, yet the majority of these genes will be 'switched off' or inactivated leaving just a few functional genes which may be transcribed to form mRNA under certain conditions. This allows for the specialisation of cells for particular tasks related to the production of particular polypeptides. The term 'gene expression' is used to describe the situation in which a gene is transcribed to produce its polypeptide.

The means by which gene expression is regulated is still unclear. Studies in prokaryotic (bacterial) cells have suggested that **regulator** and **operator** genes exist which regulate the activity of structural genes. More recently it has been suggested that stretches of DNA immediately adjacent to genes and known as **gene promoters** play a role in gene expression.

Since enzymes are proteins their production is also controlled by factors regulating gene expression. This ensures that enzymes are synthesised in correct amounts at correct times. In some cases the substrate of an enzyme will act as a stimulus to gene expression, activating the gene and allowing production of the appropriate enzyme. An example of this is seen in the bacterium *E. coli* where the substrate lactose activates the genes coding for the enzymes  $\beta$ -galactosidase and lactose permease. In other cases, accumulation of the product of an enzyme catalysed reaction may inhibit further enzyme synthesis through inhibiting the activity of a gene. An example in *E. coli* is the accumulation of the amino acid tryptophan inhibiting the production of the enzyme tryptophan synthase.

### ◆ CHECKPOINT SUMMARY

- ◆ Nuclear DNA with the genetic code never leaves the nucleus in eukaryotic cells.
- ◆ The genetic code for a polypeptide (a gene) is copied (transcribed) into mRNA which leaves the nucleus and associates with the ribosomes.
- ◆ The ribosomes 'read' (translate) the genetic message on the mRNA, and tRNA deliver amino acids in the sequence determined by the code.
- ◆ There are 20 different types of tRNA, each specific to a particular amino acid.
- ◆ Each tRNA has a specific binding site at which the specific amino acid combines and an anti-codon which matches the specific codon for that particular amino acid.
- ◆ The amino acids combine by means of peptide bonds to give a polypeptide chain.
- ◆ The polypeptides subsequently form proteins.
- ◆ As enzymes are proteins their synthesis is controlled by DNA.

## GENE MANIPULATION by BIOTECHNOLOGY

Imagine how simple life would be if there were only one type of computer and only one type of software. All the machines could then use the same language and all the information would be interchangeable. This is exactly how it is with the language of the genes. The synthesis of polypeptides from amino acids relies on exactly the same DNA and mRNA codons in every living organism, so for example, 'GCG' codes for the amino acid alanine and 'CGA' codes for arginine whether it occurs in a human, a honey bee or a mushroom. Now that genes can be identified and isolated, gene technology is providing a means of transferring them from one organism to another.

'Genetic engineering' (**genetic modification**) refers to the processes and techniques by which genes may be extracted from the DNA of one organism and inserted into the DNA of another organism (the **host** organism). In this way, the gene set (**genome**) of the host can be genetically modified (**transformed**). Thus genes from human DNA have been inserted into bacteria, and genes from bacteria into plants etc. Gene technology relies on the fact that the genetic language is universal; the 'software' (genes) can be used in any living organism. The difficulty lies in the cutting and pasting and you must first become familiar with three enzymes which are crucial to the process.

**Reverse Transcriptase** is an enzyme which makes a single strand of DNA from an RNA template (the reverse of the normal transcription process). From this strand of DNA, a complementary strand can be assembled with the aid of DNA polymerase. Reverse transcriptase enzyme was identified and isolated from **retroviruses**, a group of viruses which includes the HIV virus. This group of viruses have no DNA and their genetic information is carried in RNA. When retroviruses invade cells their RNA genome uses reverse transcriptase to make a piece of DNA. This becomes incorporated into the host cell's own DNA, and directs the production of viral products (an example of natural genetic modification).

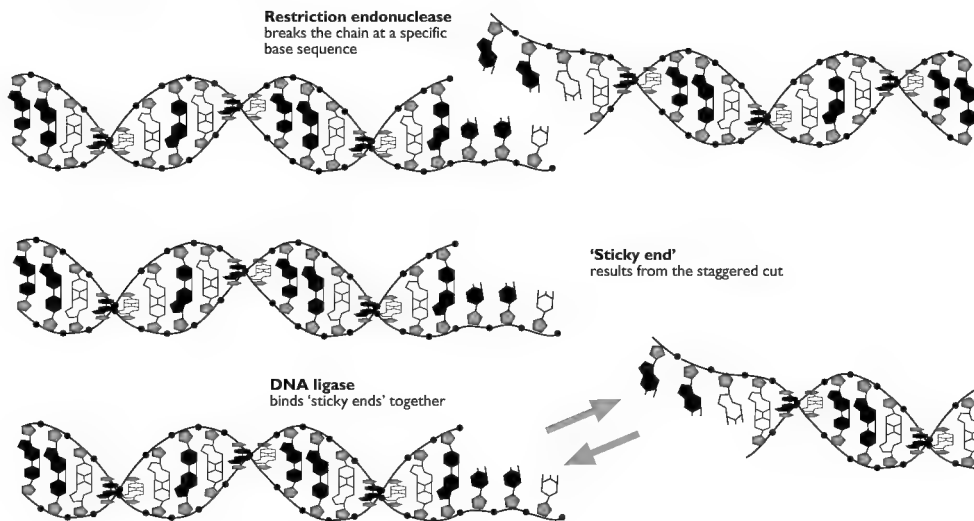
Reverse transcriptase is used in gene technology to make DNA from mRNA. Remember that mRNA is a copy of a single gene and that mRNA of a working gene may be found in the cytoplasm of a cell. It is therefore possible to isolate a gene in the form of mRNA and then to multiply it using a combination of reverse transcriptase and DNA polymerase. This is a lot easier than searching for a particular section of DNA (gene) in the nucleus.

**Restriction enzymes** (restriction endonucleases) are another vital enzyme 'tool' in genetic engineering. They cut DNA at specific base code sites into smaller polynucleotide fragments. There are many different types of restriction enzyme, each of which is specific to a particular base sequence in DNA, only cutting the DNA at these base sequences. Restriction enzymes are extracted from bacteria where they serve to protect the organism from invading viral DNA. In gene technology they are used to cut DNA into fragments which can be separated and isolated. Often the cut leaves '**sticky ends**'.

**DNA ligase** is a joining enzyme. It is used to stick the sticky ends of DNA fragments together creating new combinations (**recombinant DNA**).

The techniques for transferring genes from one organism to another can be considered in five main stages.

#### Action of restriction and ligase enzymes



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### Stage one: isolation of the required gene

It is surprisingly easy to extract DNA from living cells as you may already have discovered in the laboratory. Using restriction enzymes to cut the DNA at the desired sites, and gel electrophoresis, it is possible to separate and isolate different DNA fragments, even single genes. Alternatively, genes can be extracted from cells in the form of mRNA as described above and converted into DNA using reverse transcriptase.

### Stage two: the use of a vector

A vector is a carrier. The most common vectors in gene technology are bacterial plasmids and bacteriophage viruses both of which can carry the required gene into the host cell.

**Plasmids** are tiny rings of DNA found in the cytoplasm of bacterial cells, and which are not part of the main bacterial chromosome. They are easily transferred from one bacterial cell to another. Plasmids can be cut at specific sites using restriction enzymes to leave sticky ends. If the same enzyme is used on the isolated gene then the sticky ends will match and the two can be joined using DNA ligase so that the plasmid contains the recombinant DNA.

**Bacteriophages** are viruses which infect bacteria. They have a simple loop of DNA which they inject into the bacterial cell. This ring of DNA resembles a plasmid and can be modified in the same way to contain the required gene.

### Stage three: transformation of the host cells

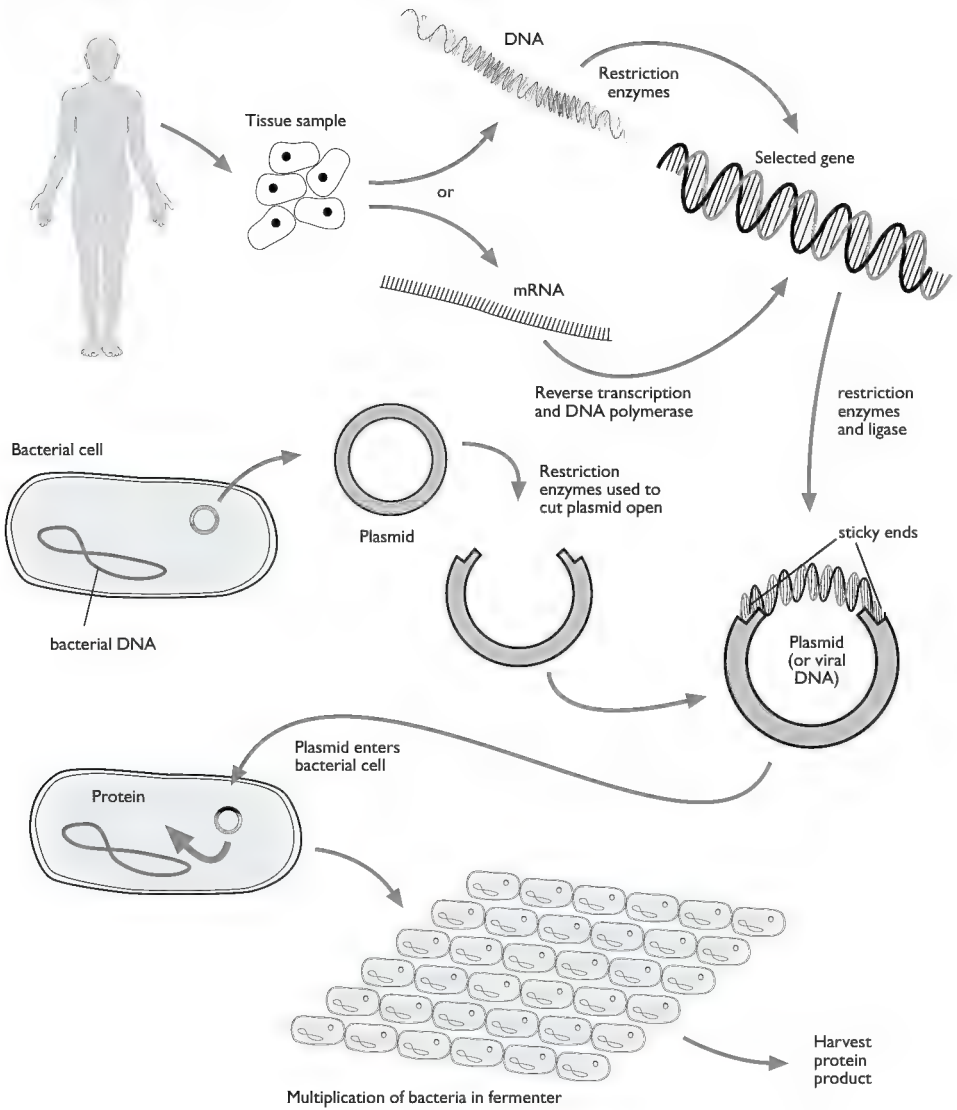
The vector is now brought into contact with the host cells in the hope that some of the recombinant DNA will be taken up by the host cells. In order to discover whether or not the host cells have taken up any of the recombinant DNA, that is whether they have been **transformed**, **marker genes** (selection genes) are used. These are genes which are engineered into the vector alongside the required gene. They do not harm the host cell in any way but code for products which show up in an easily identifiable form in the host cell, confirming that the process of transformation is complete. One of the more common marker genes codes for antibiotic resistance. The transformed host cells can be isolated by introducing an antibiotic to the culture. All non-transformed cells are killed by the antibiotic.

There has been some concern expressed about the use of antibiotic resistant genes. Opponents of this technique point to the risk of such genes escaping and entering disease organisms. Imagine the potential of disease-causing bacteria, genetically modified to resist antibiotic treatment.

### Stage four: multiplication of transformed cells

Once a cell or group of cells has been persuaded to take up recombinant DNA, the next step is to culture the cells in a suitable growth medium, allowing them to grow and multiply. In the case of transformed bacterial and yeast cells, this can be done on a large scale in industrial **fermenters** allowing the product(s) of the new gene to be harvested and purified, as in the case of insulin, and blood clotting factor VIII.

## Gene manipulation (biotechnology)



## Synthesis of human factor VIII

Factor VIII is a vital blood clotting factor lacking in people suffering from the inherited disease haemophilia. People with this disease have blood which clots very slowly. As a result they are at risk from excessive bleeding, especially internally. Originally factor VIII used in the treatment of haemophilia was extracted from blood provided by blood donors. However, there have been scandals in which factor VIII contaminated with HIV was supplied to several thousand haemophiliacs. Now the gene for factor VIII has been engineered into yeast cells, and like insulin it is now produced cheaply, in large quantities, with no risk of contamination.

## Synthesis of human insulin

**Insulin** is needed by people who are unable to produce sufficient quantities of the hormone and therefore suffer from diabetes mellitus. This is a condition, affecting 2% of the population, in which blood glucose rises to dangerous levels after meals. This can have serious effects on many systems within the body, including the kidneys and the eyes. Before gene technology, the only source of insulin was natural. It was extracted from the pancreases of pigs and cattle. This was not ideal because human insulin is slightly different in chemical structure, and although the pig and cattle version works on glucose in a similar way, some people are allergic to it, and the extraction process is both costly and open to contamination by impurities.

In the early 1980's the gene for human insulin was transferred from human pancreas cells to *E. coli* bacteria. Bacterial colonies modified in this way were cultured for mass production in industrial fermenters providing a constant supply of insulin. Now most insulin is produced by transformed bakers' yeast cultures. Yeast has various advantages over bacteria. It does not produce any toxic by-products, it can be grown on simple nutrient media, and it can secrete the finished product directly into the culture medium making extraction easier.

### ◆ CHECKPOINT SUMMARY

- ◆ Isolation of the gene to be manipulated is the first step
- ◆ It is easier to find and isolate the appropriate mRNA which has been transcribed (copied) from the relevant DNA, than it is to try and isolate the particular length of DNA itself.
- ◆ The enzyme reverse transcriptase can then be used to make a copy of the DNA from the mRNA.
- ◆ Plasmids (circular DNA) are isolated from bacteria.
- ◆ Plasmids are cut open by restriction enzymes, the length of DNA is inserted, and the plasmid resealed by ligase enzymes.
- ◆ The genetically modified plasmids are then reintroduced into the bacteria.
- ◆ The bacteria multiply and produce the protein coded for by the inserted DNA.
- ◆ To identify those bacteria which have successfully taken up the modified plasmids, marker genes are incorporated along with the required gene.
- ◆ Marker genes include those for antibiotic resistance so that the culture can be flooded with antibiotic and only the bacteria with the marker gene will survive.
- ◆ Two early successes with these techniques were the synthesis of human insulin for the treatment of diabetics, and blood clotting factor VIII for the treatment of haemophiliacs.

## 1.6

# Nuclear Division

### Content

- ▼ Replication and division of nuclei.
- ▼ Chromosome behaviour in mitosis.
- ▼ The need for reduction division in sexual reproduction.

Candidates should be able to:

- explain how growth, repair and asexual reproduction in animals and plants can be brought about by mitosis.
- explain the need for the production of genetically identical cells.
- explain how cancer is the result of uncontrolled cell division, and list factors that can increase the chances of cancerous growth.
- describe, with the aid of diagrams, the behaviour of chromosomes during the mitotic cell cycle, and the associated behaviour of the nuclear envelope, cell membrane and centrioles. (Names of the main stages are expected.)
- explain what is meant by homologous pairs of chromosomes.
- explain the meaning of the terms haploid and diploid, and the need for a reduction division prior to fertilisation in sexual reproduction. (Details of meiosis are not expected.)

### NUCLEAR DIVISION by MITOSIS

New cells (daughter cells) are formed by cell division. In the case of single celled organisms this is called **binary fission**. Cell division is initiated by the nucleus, and nuclear division is the first visible sign of the process of cell division. The commonest form of nuclear division is that of **mitosis** in which two genetically identical daughter nuclei are formed. Mitosis occurs in the cell division seen in growth, repair, the replacement of cells which have a limited life span like our red blood cells and skin cells, and in asexual reproduction in many plants and lower animals. The development of a multicellular organism from a fertilised egg by mitosis, means that all the cells of the body are genetically identical to the fertilised egg. The development of an organism from the fertilised egg is the story of the controlled expression of genetic information, with only a small fraction of the genes being expressed in cells as they differentiate to form tissues specialised for specific (and limited) functions. In mature cells most of the DNA is inactive all of the time.

Asexual reproduction does not involve the fertilization of gametes, and as a result of mitosis produces offspring which are genetically identical to each other (**clones**). Many multicellular organisms, especially plants, can reproduce their entire bodies in this way, either from specialised structures eg. strawberry runners, or single celled spores.

#### ◆ CHECKPOINT SUMMARY

- ◆ Mitosis is nuclear division in which two daughter nuclei with the same chromosome number as the parent nucleus are produced, typically diploid nuclei producing diploid daughter nuclei.
- ◆ The daughter nuclei are therefore genetically identical to the nucleus of the cell that produced them (except for any mutations that may occur).
- ◆ Mitotic cell division is seen in growth, repair and asexual reproduction.
- ◆ As a result of mitosis in the growth of an organism from the fertilised egg, all cells are genetically identical.
- ◆ Similarly, offspring of asexual reproduction lack genetic variation.

## The NEED for GENETICALLY IDENTICAL CELLS

The production of genetically identical cells in the growth and development of multicellular organisms allows certain cells to retain the ability to develop into any other if needed, for example stem cells in mammals can divide to form any of the different types of blood cell. In the asexual reproduction of organisms it allows for the rapid exploitation of optimal conditions, where any variation would be disadvantageous.

## CANCER and FACTORS that INCREASE its CHANCES

Cancer is the general name given to a diverse group of diseases which are characterised by unregulated cell division and the formation of tumours (large masses of cells which are abnormal in appearance and have arisen from a single precursor cell.)

Cancer is essentially a genetic disease in that it results from mutations in genes encoding proteins regulating the normal growth of cells and the cell cycle. There are three main types of gene which, if they acquire mutations, may result in transformation of a normal cell to a tumour cell.

**Proto-oncogenes:** in the normal cell, these genes encode for products that are involved in stimulating normal cell division, cancer might result from activation of one of these growth promoting proto-oncogenes.

**Tumour suppressor genes:** in the normal cell these genes encode for proteins which suppress cell growth. It is thought that many of these genes encode proteins which suppress DNA synthesis. Thus a mutation in one of these suppressor genes may result in production of a defective protein and loss of suppression of cell growth and division.

**Genes regulating cell death (apoptosis):** as well as strict regulation of cell division, the death of cells is also closely regulated. The body may wish to destroy cells in order that they can be replaced by newer ones, or at other times it may wish to destroy cells that are now no longer required, such as the breast tissue after the menopause. This programmed cell death is referred to as apoptosis. Disruption of the genes encoding proteins involved in apoptosis may cause cells to escape programmed cell death and continue to divide to form a tumour.

## Factors which increase the risk of cancer

The genetic mutation or mutations that cause cancer may arise by chance. However, there are certain groups of people who are more at risk of acquiring these mutations and consequently cancer itself:

**Familial (hereditary):** certain mutant genes may be passed from one family member to the next. This form of inherited cancer is rare. Certainly more commonly, an **increased risk** of cancer is inherited. For example, a man whose mother has bowel cancer, is himself four times more likely to develop bowel cancer.

**Environmental:** certain chemicals damage DNA. A chemical that increases the risk of developing a cancer is referred to as a **carcinogen** or as being **carcinogenic**. Carcinogens are found in cigarette smoke and in low levels in some common foods and food additives. Radiation in the form of ultra violet light, gamma rays and X-rays is also carcinogenic. It damages DNA and malignant transformation is more likely. Environmental factors may also include certain viruses and other pathogens which have been linked to increased risk of cancer.

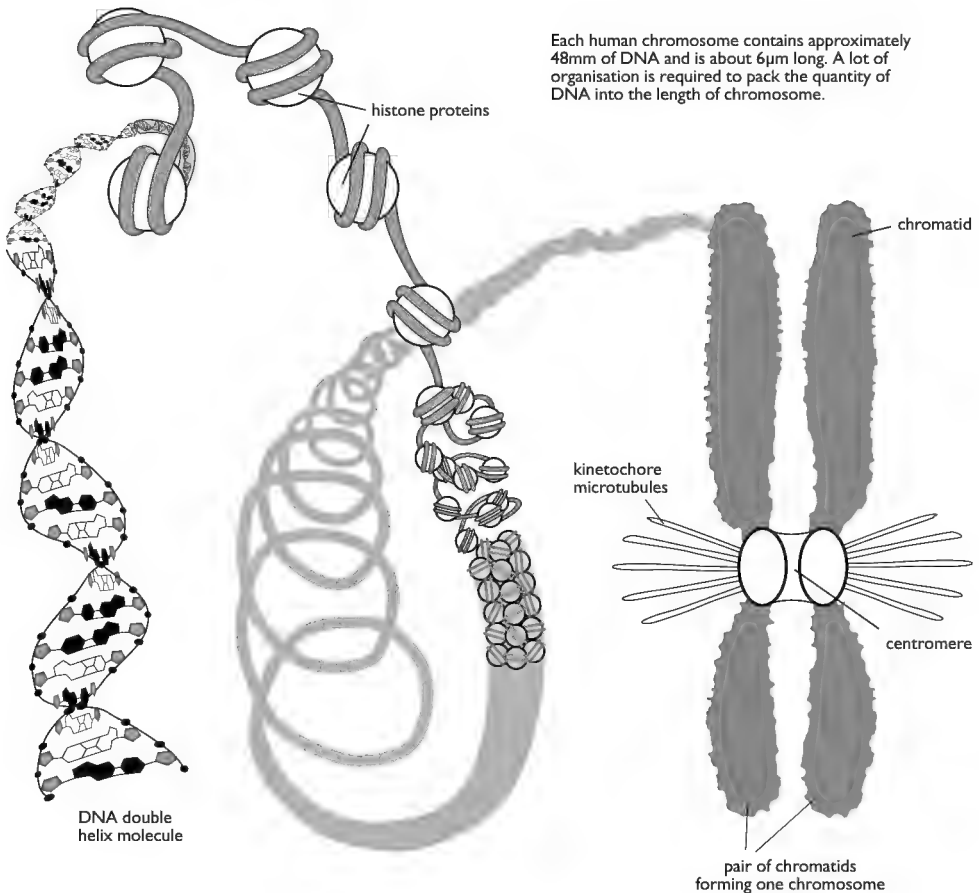
## The MAIN STAGES of MITOSIS

Chromosomes only become visible when stained and viewed under the light microscope when the nucleus of a cell is just about to divide. This is because only at this time is the DNA/histone mixture wound up (condensed) as tightly as it can be. By this stage the DNA has also copied itself (replicated) so each chromosome appears double, and joined at one point (the **centromere**). Whilst they remain joined in this way the two daughter chromosomes are referred to as **chromatids**.

### ◆ CHECKPOINT SUMMARY

- ◆ Cancer is the result of uncontrolled mitotic cell division.
- ◆ Any factor that disrupts normal control of mitosis increases the chances of cancerous growth e.g. ultra-violet light, X-rays, and carcinogenic chemicals, e.g. tar, benzene.

Diagram showing how DNA is organised into a chromosome





## Main stages of the mitotic cell cycle

Nuclear division (mitosis) occurs in four main stages, namely prophase, metaphase, anaphase and telophase.

**Prophase** is the first phase of mitosis, and as it begins, the DNA has already replicated, all protein synthesis has stopped, and each chromosome is condensed into the characteristic double chromatid, form. At the same time the cell rounds up, the nuclear membrane breaks down into small fragments, and a **spindle** of microtubules forms between two **microtubule organising centres (MTOCs)** at opposite poles of the cell.

**Metaphase** is defined as when the chromatids become attached to the spindle by structures called **kinetochores**. Kinetochores consist of microtubules and 'motor' proteins which utilise ATP energy to pull on the spindle. The effect of both sets of kinetochores pulling in opposite directions is that the chromosomes line up along the middle (equator) of the spindle.

**Anaphase** is defined when quite suddenly, and all at once, the chromatids of each pair separate, with each being pulled under tension in opposite directions towards the poles of the cell.

**Telophase** is the stage when the two new, identical sets of chromosomes reach the opposite poles and a new nuclear envelope forms to surround each set.

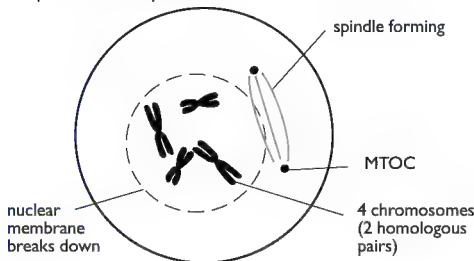
### ◆ CHECKPOINT SUMMARY

- ◆ The DNA replicates in interphase so that in the first stage of mitosis (prophase) the chromosomes appear as double structures of two chromatids (daughter chromosomes) joined at the centromere.
- ◆ The nuclear spindle apparatus(NSA) forms from the dissolution of the nuclear membrane and the centrioles replicate and migrate to either pole of the NSA.
- ◆ The centromeres align on the equator of the NSA (metaphase).
- ◆ The centromeres divide and the chromatids are moved to the opposite poles (anaphase).
- ◆ Two new daughter nuclei are formed (telophase).

### Diagram to show stages in mitosis

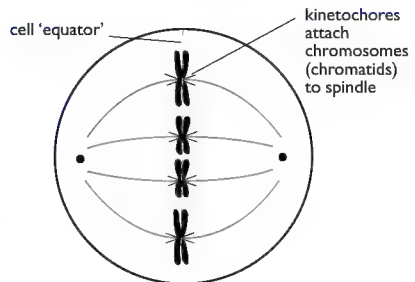
#### 1 Prophase

Cell is rounded  
MTOC's migrate to opposite poles  
nuclear membrane disintegrates  
spindle formed by MTOCs



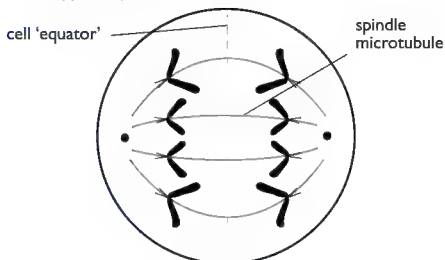
#### 2 Metaphase

Chromosomes held on 'equator' of cell  
under tension. MTOCs at opposite poles



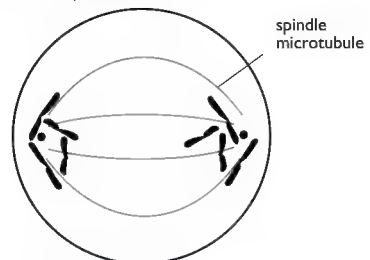
#### 3 Anaphase

Chromatids separate and move towards opposite poles



#### 4 Telophase

Beginnings of new nuclei at opposite poles  
nuclear envelope reforms

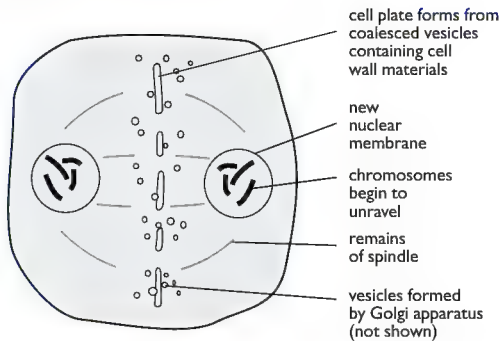


Nuclear division by mitosis is followed by division of the cytoplasm into two equal parts. This process is called **cytokinesis** and it occurs differently in animals and plants. In animal cells the spindle disintegrates during telophase and the microtubule components reassemble into a new cytoskeleton. The equator of the cell is constricted by a ring of contractile proteins (actin) in the process of cleavage, to create two roughly equal cells.

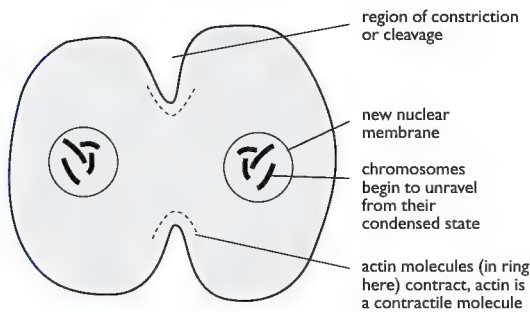
In plant cells the spindle lingers a little longer and seems to act as a guide to bring Golgi apparatus and associated secretory vesicles to the equator. The vesicles deposit their contents, which are the building constituents of a new cell wall, on the equator to form a plate of deposited material (the **cell plate**). Some of the vesicles remain intact and make connecting channels through the new cell wall (plasmodesmata).

**Diagram showing the process of Cytokinesis**

#### Cytokinesis in plant cells



#### Cytokinesis in animal cells



**Interphase** refers to the greater part of the life of a cell when there is no visible activity. The periods of mitosis and cytokinesis occupy only a fraction of the entire life of a cell. Together, interphase, mitosis and cytokinesis make up the **cell cycle**. The term interphase should not be interpreted to mean that the cell is resting. Interphase can itself be divided into three distinct periods called G1, S and G2. ('G' refers to the 'gaps' between DNA replication and mitosis.)

**G1** is by far the longest period of the cell cycle. During G1, the cell machinery carries out protein synthesis, and growth occurs. All the cells of the body have identical sets of genes in their nuclei but the cells develop in different ways to perform different functions. This development process is called cell **differentiation** in which different genes are switched on and off so that only one small part of the genetic code is active in each cell.

After a period of growth and differentiation, the length of which depends upon a variety of internal and external factors, protein synthesis is suspended, and the DNA set replicates itself. This is the **S** phase. DNA replication is followed by another 'gap' period, **G2**, before mitosis starts, in which the cytoskeleton of the cell breaks down and the microtubule components begin to reassemble into spindle parts. Without a cytoskeleton, the cell assumes a more spherical shape (see prophase).

The timing of events within the cell cycle is extremely variable. In ideal conditions, where food and oxygen are in plentiful supply and temperature and pH values are optimal, bacterial cells can complete the cycle to produce a new generation every 20 minutes. Other cells, for example muscle cells, never complete the cycle and remain stuck in G2 until they die, a condition called **terminal differentiation**.

It has become clear that the onset of the S (DNA replication) phase and the M (mitotic) phase are determined by genes which are very similar in all organisms. These genes direct the synthesis of enzymes which in turn activate the enzymes initiating S and M phases.

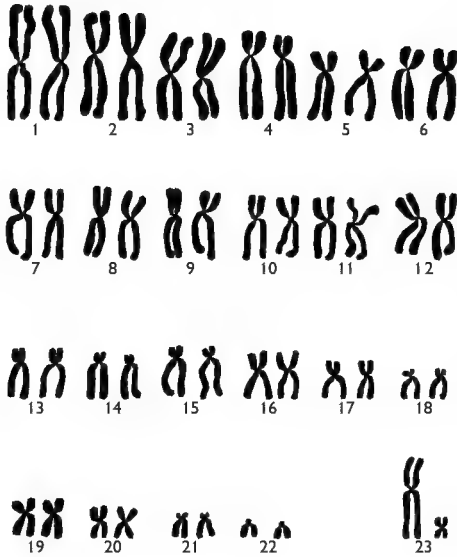
The rate of cell division can be controlled by naturally occurring plant substances which affect the process of nuclear spindle formation. These include **vincristine** and **vinblastine** (from the periwinkle plant *Catharanthus rosea*). Both of these substances are used to control cancers such as leukaemia and lymphoma. They work, at a molecular level, by binding on to the spindle microtubules, preventing spindle assembly.

The plant substance, **taxol**, from the Pacific Yew (*Taxus brevifolia*) has almost the reverse effect on spindle formation, causing an over production of microtubules which effectively stops cell division. Taxol has been used to treat ovarian cancers.

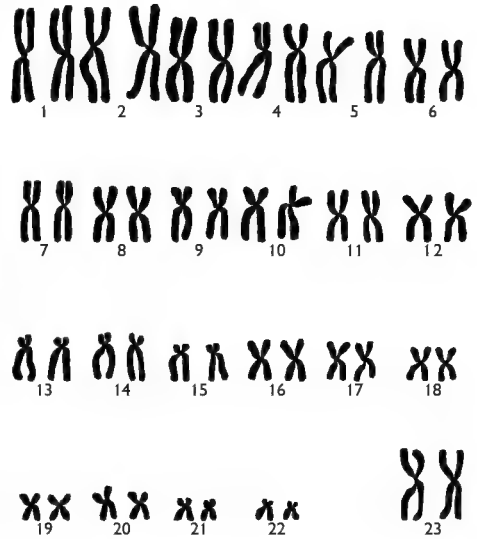
## HOMOLOGOUS PAIRS of CHROMOSOMES

The DNA in eukaryotic cells is combined with **special nuclear proteins (histones)** to form 46 separate chromosomes. These 46 chromosomes constitute what is called the human **karyotype**. The 46 chromosomes exist as two sets of 23 chromosomes, one set of which is inherited from the mother's egg, and the other set from the father's sperm. The chromosomes of a pair have the same shape and structure and carry copies of the same genes (albeit often in a slightly modified form or **allele**). The chromosomes of a pair are said to be **homologous**. The sex chromosomes (X and Y chromosomes) are only partially homologous and carry different genes on their non-homologous 'arms', e.g. the Y chromosome carries male determining genes which are not found on the X chromosome.

Karyotype normal human male



Karyotype normal human female

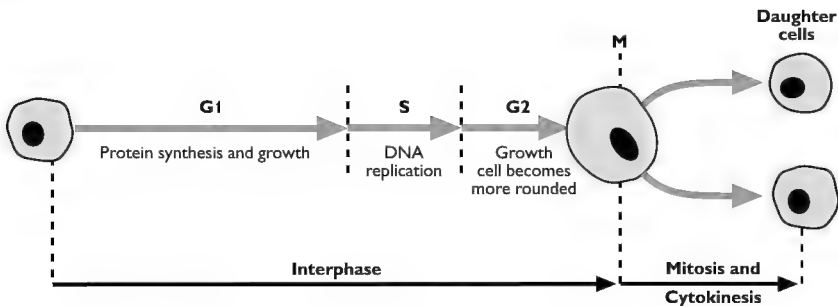


### Learning Objective (1)

#### NEED for REDUCTION DIVISION PRIOR to FERTILISATION in SEXUAL REPRODUCTION

The only cells in the body which do not possess the double (**diploid**) set of homologous chromosomes are the gametes, which are **haploid**, meaning they only contain one of each pair. The nuclear division that produces haploid gametes is called **meiosis** which you will study later in the course. (Note the abbreviations,  $2n$  = diploid,  $n$  = haploid)

#### The cell cycle



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## 1.7

# Energy and Ecosystems

### Content

- ▼ Energy transfer through an ecosystem
- ▼ The nitrogen cycle

#### Learning Objective 1

Candidates should be able to:

- define the terms habitat, niche, population, community and ecosystem, and state examples of each.
- explain the terms producer, consumer and trophic level.
- describe how energy is transferred through food chains and food webs, and discuss the efficiency of this transfer between trophic levels.
- describe how nitrogen is cycled within an ecosystem. (Reference should be made to the roles of microorganisms, but only *Nitrosomonas*, *Nitrobacter* and *Rhizobium* need to be identified by name.)

#### Learning Objective 2

### HABITAT, NICHE, POPULATION, COMMUNITY and ECOSYSTEMS

The biosphere is the name given to that section of the planet which can be inhabited by living organisms. It extends from about 600m above sea level to about 10 000m below sea level and includes regions as different as the polar ice caps and hot volcanic springs although these extreme environments can be exploited by only a few specialised life forms.

### Habitats

Each living organism has its own habitat ('address') within the ecosystem. A habitat must provide three essential things which the organism needs to survive. Firstly, it must supply food through all seasons of the year. It must also offer protection from extremes of climate and from other organisms. Finally, it must provide a place to breed, for example, nesting sites and materials for nest building. For an earthworm or a dandelion all these needs can be supplied by a small area of garden soil. Larger animals require much greater areas of ecosystem. Elephants travel many miles to satisfy their need for food and water and eagles require large hunting areas with isolated and protected nesting sites. It is small wonder that the creatures with the largest habitat requirements are under the greatest threat from expanding human populations.

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## Niches

Different animals and plants must occupy their own **ecological niche** if they are to coexist in the same habitat. If two populations shared exactly the same habitat requirements, then they would compete for everything; food, protection and breeding sites, with the result that one or both populations would be eliminated. To survive in the same habitat, different populations must occupy slightly different niches. A good example of 'niche differentiation' is provided by two birds which inhabit rocky coastal waters, the shag and the cormorant. The two species look similar and both dive for their food. The difference is that cormorants feed on bottom dwellers like prawns and flatfish whilst the shag picks up prey nearer the surface. In this way they avoid competition. Each has its own ecological niche. You will see in later sections that niche differentiation is thought to be an important driving force in the process of evolution.

## Populations

The total number of individuals of any particular species within a community is termed a population.

## Communities

Communities are composed of many different populations. The term community refers to the entire set of organisms which coexist within a particular ecosystem.

## Ecosystems

Most organisms exist in mixed communities within defined, and more or less self-contained, sections of the biosphere referred to as **ecosystems**. Terrestrial ecosystems are characterised by a particular type of vegetation, for example, grassland or coniferous forest. Aquatic ecosystems are defined by the type of water: fresh, salty, still or running. An ecosystem consists of three interrelated components: **biotic** (the community of living organisms), **climatic** (temperature, rainfall light etc.) and **edaphic** (soil factors).

Each of these components is dependent on the other. In a forest for example, the trees depend on the soil for minerals but the soil is made stable and fertile in return by the plant roots and dead remains. The trees also depend on the climate for light and water but rain clouds are made up of water vapour, some of which has been transpired from the tree leaves.

A typical ecosystem such as a pond or forest, consists of populations of predators, herbivores, plants, parasites and decomposers.

**Decomposers** are microorganisms, mainly bacteria and fungi, which consume dead materials extracting energy from them and releasing simple reusable substances such as mineral ions back to the environment. They are essential to any ecosystem because they ensure that nutrients are recycled.

### ◆ CHECKPOINT SUMMARY

- ◆ The three primary 'drives' - to feed, to protect, and to reproduce, must be satisfied by the habitat e.g. leaf litter in a woodland.
- ◆ Niche refers to the role of the organism within the habitat e.g. leaf feeder or detritivore in the leaf litter in a woodland.
- ◆ A population is a collection/association of typically interbreeding members of the same species.
- ◆ Communities consist of all the different populations that coexist within an ecosystem.
- ◆ An ecosystem is a more or less well defined region in which three components: biotic (living organisms), climatic, and edaphic (geology, soil and water) interact e.g. a fresh water pond.
- ◆ All of these definitions are fairly arbitrary and artificial with many overlaps and anomalies.
- ◆ They are only useful if they clarify discussions of problems in ecology, and too much emphasis should not be put on their definition for its own sake.
- ◆ Migration amongst animals further blurs the boundaries of many of these arbitrary divisions.

## Learning Outcome (b)

### Producers, consumers and trophic levels

All of the food materials generated within an ecosystem are manufactured by **autotrophic** (self feeding) organisms which can produce organic compounds from simple inorganic substances using an external source of energy. These organisms are called **producers**. Green plants are the most important producers because they convert light energy to chemical energy and make it available to other organisms referred to as **consumers**. Consumers are **heterotrophic** organisms which cannot produce their own food and must obtain a supply of ready-synthesised organic compounds from other organisms.

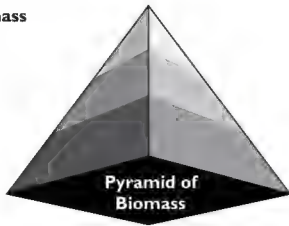
The organic substances are passed from organism to organism through **food chains**. If the different consumers in an ecosystem are arranged in their feeding sequence (**trophic level**), from producers to herbivores to carnivores they form a **pyramid of biomass** where the producers form the largest mass and the top carnivores, the smallest. However, it must be remembered that many organisms feed at more than one trophic level, for example a cormorant feeding on shrimp (herbivores at trophic level one) may also feed on fish (carnivores at trophic level two) that eat shrimps. Food chains rarely exist in isolation, and there are typically many interconnections with other food chains, to form **food webs**.

#### Pyramid of biomass

Carnivores

Herbivores

Plants in old fields

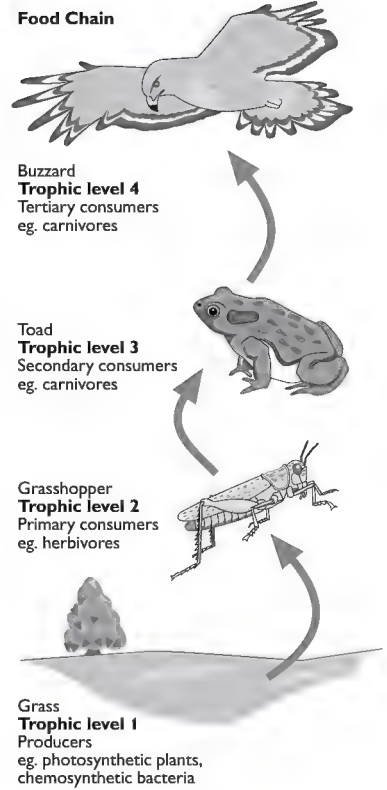


0.1 g dry wt m<sup>-2</sup>

0.6 g dry wt m<sup>-2</sup>

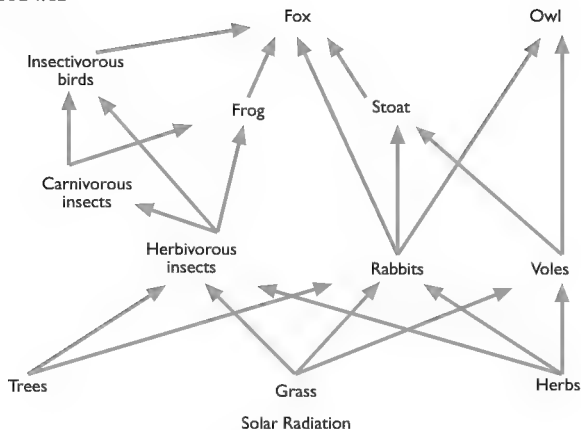
470 g dry wt m<sup>-2</sup>

#### Food Chain



Arrows represent flow of energy

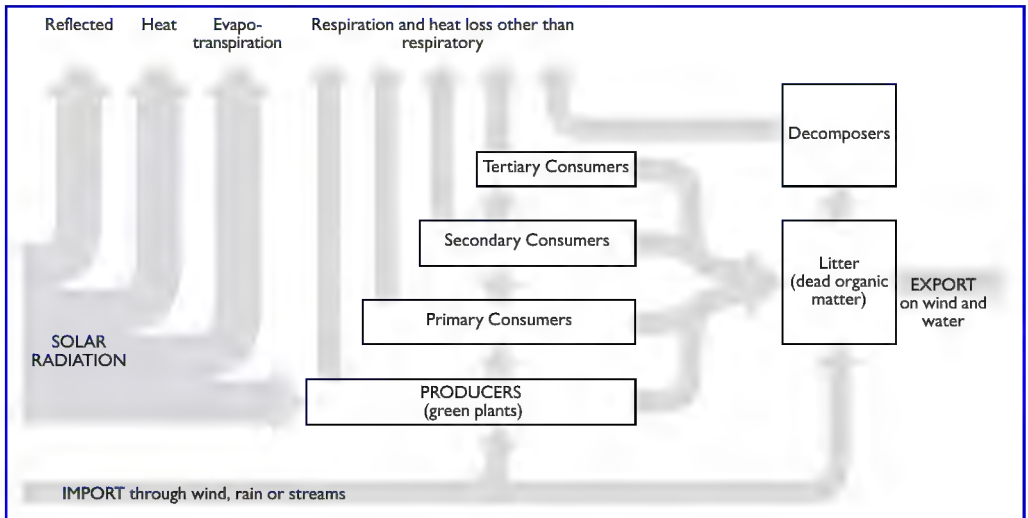
#### Food web



## ENERGY FLOW THROUGH ECOSYSTEMS

Some of the chemical energy in the organic substances passing through food chains or food webs remains locked in organic matter of the living organisms' bodies, and some is converted in the process of respiration to the energy rich substance ATP, in which form it is used in energy requiring processes such as movement. Eventually all the energy used in this way is released back to the environment in the form of waste heat.

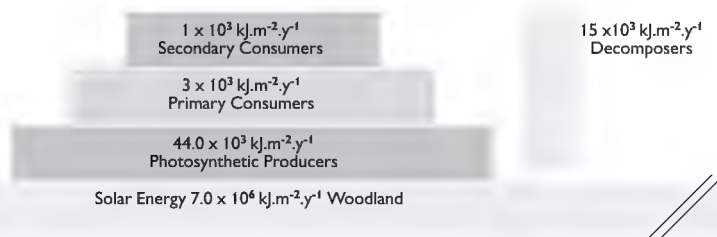
The transfer of food energy from one organism to another is always wasteful. Each organism has its own energy requirements and releases heat to the environment as it grows, moves and reproduces. Other losses occur in faeces or through nitrogenous excretion. Note that energy conversions work in one direction only, the sun's energy is not recycled in ecosystems, but passes through the food webs in chemical form and out of them as heat. (Remember that energy can neither be created nor destroyed but only changed from one form to another, ultimately being liberated as heat).





The efficiency with which the plants of an ecosystem convert light into food energy is known as their **productivity**. The **gross primary production** is the total energy converted by photosynthesis into plant biomass, and is measured in  $\text{kJ}\cdot\text{m}^{-2}\cdot\text{yr}^{-1}$ . Some of this energy is lost as heat as a result of the metabolism of the plants, especially respiration. The quantity available to consumers is called the **net primary production**.

### Pyramid of energy



Although the biomass contains the energy, a pyramid of biomass is not exactly equivalent to a **pyramid of energy**, as different organic compounds have different energy contents.

## BIO-GEOLOGICAL CYCLES

Whilst energy flows through an ecosystem in one direction only and its supply must continually be renewed by the sun, the elements which make up the bodies of living organisms are fixed in quantity and have to be recycled and reused. When organisms die, their component molecules and ions are released back to the environment through the activity of decomposers. They may pass into the atmosphere as gases, enter the earth's oceans as dissolved minerals or become locked up in geological formations. Later, after just a day or two or millions of years, they may be taken up again by a producer and made once more into the components of a living organism.

### The Nitrogen Cycle

Nitrogen is a vital component of protein, ATP and nucleic acids in living organisms and makes up about 3% of the total body mass of humans. Nitrogen gas composes 79% of the atmosphere but only a select group of microorganisms called **nitrogen fixers** can actually use this source. Plants take up nitrogen in the form of nitrates and ammonium ions from the soil, combining them with carbohydrate molecules synthesised by their leaves to make the protein, nucleic acids and other compounds that they need. Most other organisms (consumers) take in nitrogen in this ready made-up form through the food chain.

The principal conversions in the nitrogen cycle are between the three 'reservoirs' of nitrogen and its compounds, namely the atmosphere, the soil (or water) and living organisms.

#### ◆ CHECKPOINT SUMMARY

- ◆ Producers 'produce' the organic matter on which all life depends, virtually all producers are photosynthetic, converting light energy from the sun into the stable chemical energy of organic compounds.
- ◆ Consumers 'consume' producers and each other to obtain a supply of ready-made organic material.
- ◆ Feeding relationships can be considered as food chains and webs with organisms at different feeding or trophic levels, although organisms can feed at more than one level.
- ◆ The efficiency of energy transfer between trophic levels is typically less than 10% due to losses in conversion.
- ◆ Photosynthetic producers only trap a small fraction of the available energy of sunlight, inefficiencies of respiration, digestion and absorption mean that most organic matter is not assimilated by consumers, with much energy lost as heat.
- ◆ The resulting loss of energy up a food chain allows organisms at different trophic levels to be represented in pyramids of biomass or energy.
- ◆ Typically there is a maximum of four trophic levels in a food chain as a result of these losses at each level.

## From nitrogen gas to ammonia (NH<sub>3</sub>) - nitrogen fixation

It is possible to make ammonia from gaseous nitrogen and hydrogen in the laboratory by combining them at high temperatures and pressures. This process is exploited commercially in the manufacture of nitrogen based fertilisers such as ammonium nitrate. **Nitrogen fixing bacteria** such as *Rhizobium* can perform the same feat at normal temperatures and pressures by means of an extraordinary enzyme called **nitrogenase**. They use the ammonia to make proteins and other organic nitrogen-containing materials. One group of nitrogen fixing bacteria, which includes *Rhizobium*, forms a mutually beneficial mutualistic relationship with plants of the bean and pea family (**Papilionaceae**). *Rhizobium* can live freely in the soil but it also penetrates the roots of these plants causing numerous nodules to grow. Inside the nodules, the bacterial cells multiply, absorbing nutrients from the plant and giving, in exchange, a supply of fixed nitrogen. This is the basis of crop rotation, in which clover or related plants are grown to replenish the nitrate content of soils depleted by previous crops, e.g. wheat.

## From organic matter to nitrates in the soil - nitrification

Dead animals and plants, excreted materials and faeces are broken down in the soil and water by decomposers such as bacteria and fungi. Proteins are digested in this process and the amino group containing nitrogen is split off from the resulting amino acids in the form of ammonia (NH<sub>3</sub>). This process is called **deamination**. The activity of decomposers results in a pool of ammonia and ammonium compounds including urea, and this can be used as an energy source by a group of bacteria called **nitrifying bacteria** which includes the organisms *Nitrosomonas* and *Nitrobacter*. In contrast to green plants which derive their energy from the sun (**photoautotrophs**), *Nitrosomonas* and *Nitrobacter* use the energy derived from chemical reactions (**chemoautotrophs**), specifically the oxidation of ammonium ions to nitrites, and nitrites to nitrates, respectively.

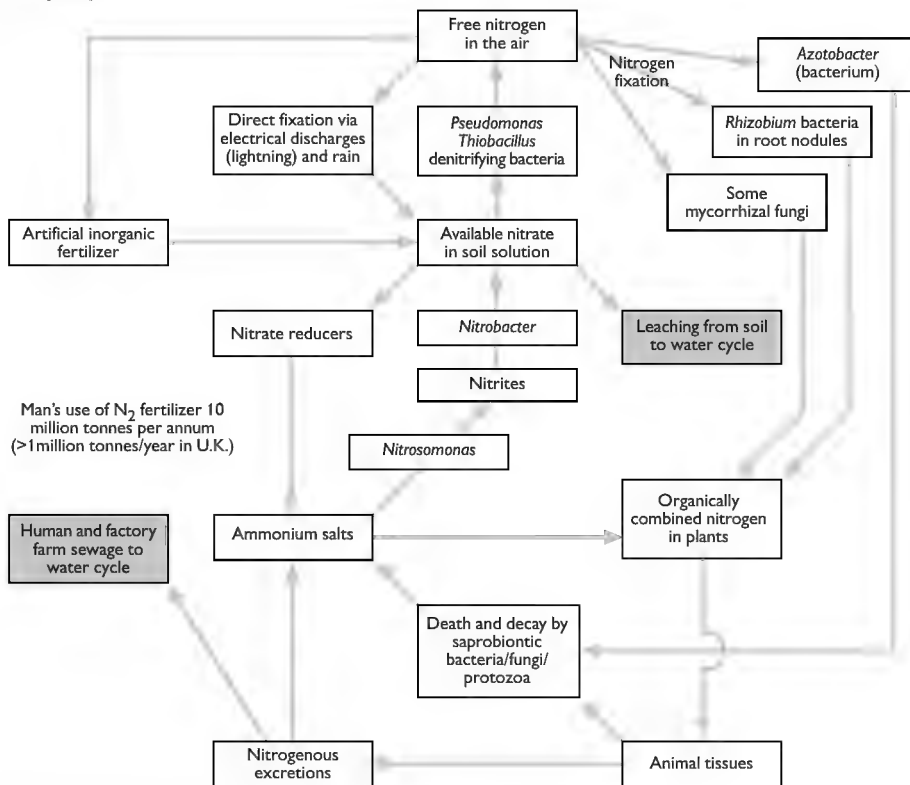
## From nitrates to nitrogen gas - denitrification

A third group of bacteria, called **denitrifying bacteria** use nitrates as a source of oxygen for their respiration. These organisms are able to survive in soils which are waterlogged and lacking in oxygen and they release nitrogen gas as a waste product to the atmosphere, completing the nitrogen cycle. In nature, nitrogen fixation occurs faster than denitrification in all but winter waterlogged soils.

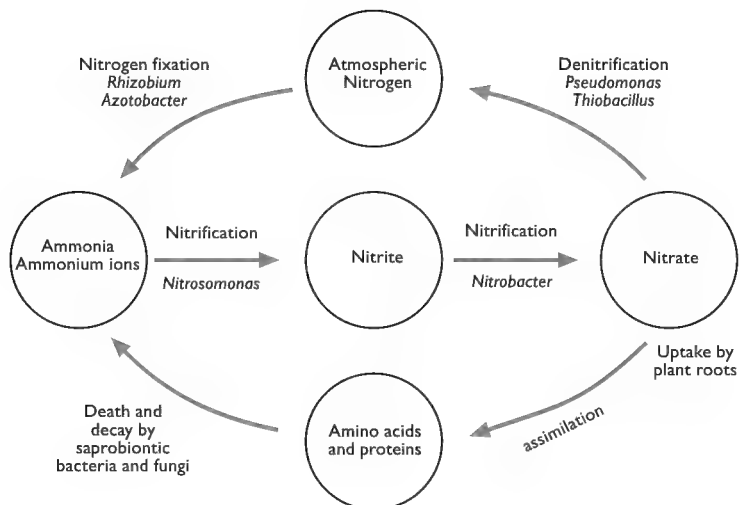
### ◆ CHECKPOINT SUMMARY

- ◆ The principle conversions in the nitrogen cycle are between the three reservoirs of nitrogen and its compounds: the atmosphere, soil and water, and living organisms.
- ◆ Nitrogen fixing microorganisms, e.g. *Rhizobium* bacteria can convert nitrogen to nitrogen containing organic compounds such as amino acids which are the building blocks of proteins.
- ◆ *Rhizobium* forms a mutualistic association in the root nodules of certain plants (*Papilionaceae*).
- ◆ Dead organic matter is decomposed and nitrogen containing compounds, e.g. ammonia and ammonium compounds are released.
- ◆ Chemosynthetic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* use these as a source of energy for their synthetic processes, and result in the production of nitrate ions.
- ◆ Plants take up ammonium and nitrate ions and combine them into amino acids and proteins, and other nitrogen containing compounds, e.g. ATP and DNA.
- ◆ Animals consume plants, and each other, and these nitrogen containing compounds form an essential part of the diets of consumers.
- ◆ Animals die and are decomposed and the cycle continues.
- ◆ Anaerobic denitrifying bacteria convert nitrates back to nitrogen.
- ◆ Man now has a considerable effect on the Nitrogen cycle by the use of artificially produced nitrate fertilisers.

## Nitrogen cycle



## Simplified version of nitrogen cycle



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## Human influences on the nitrogen cycle

Human activities add large amounts of nitrogen compounds to the soil and water. There are three main sources of this extra fixed nitrogen: fertilisers, animal excreta and domestic sewage, all of which lead to unnaturally high levels of nitrates in the water which may drain off the land and enter rivers and lakes. When the nutrient content of water is increased in this way it is known as **artificial eutrophication**. High nitrate levels in rivers and lakes stimulate the rapid growth of water plants, particularly microscopic algae (especially when phosphates are also present). The growth of algae can be so extreme as to cause **algal blooms** which block out the light for other photosynthesising life forms and clog up filters in water purification plants. The end result of so much plant life is an equivalent excess of dead plant material which, in turn, stimulates a population explosion of aerobic decomposing bacteria. As the bacteria multiply and respire, they use up the available oxygen supply in the water. Ultimately animals which require high oxygen levels, e.g. fish and insect larvae, die. As oxygen levels continue to decrease, there is an increase in anaerobic microorganisms. Still water of this type becomes stagnant and smells of methane and hydrogen sulphide, the waste products of decomposition by anaerobic bacteria.

The process of eutrophication occurs naturally in lakes which gradually accumulate increasing quantities of inorganic nutrients from their feeder streams and rivers. Artificial eutrophication, however, is a vastly accelerated process. It is estimated, for example that lake Erie in Canada would have taken another 15 000 years to reach the its present state of eutrophication had it not been for the activities of humans.

Potentially, nitrates are one of the most serious of all pollutants in drinking water, as the soluble forms are not removed by the usual treatment processes. There are vast amounts of nitrates slowly percolating down towards the underground water stores or **aquifers** which provide about 30 % of the water supplies in Britain. As more and more aquifers become polluted with dangerous levels of nitrate, increasing attention will have to be paid to the problems of nitrate removal at water purification works. Nitrates can be reduced to nitrites in the anaerobic conditions of the gut (particularly in the only slightly acid stomach of babies). The nitrites can oxidise the iron in red blood cell haemoglobin to a form which cannot transport oxygen. This can produce a fatal anaemia in infants. Another danger is that of nitrites reacting with other compounds in the gut to form cancer forming **nitrosamines**.

# Biology



## **2 Human Health & Disease**

**FELTHAM PRESS**

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## 2 Human Health and Disease

### 2.1.

### Introduction to health and disease

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#### Content

- ▼ Definitions of the terms health and disease.
- ▼ Global patterns of disease distribution.



Candidates should be able to:

- a) discuss what is meant by the terms health and disease.
  - b) discuss whether health is more than simply the absence of disease.
  - c) explain, with one example of each, what is meant by the following categories of disease or illness: physical, mental, social, infectious, non-infectious, degenerative, inherited, self-inflicted and deficiency.
  - d) explain the reasons for collecting health statistics.
  - e) describe and explain the differences between standards of health in developed and developing countries.
  - f) explain the terms pandemic, epidemic and endemic.
  - g) appreciate the significance of the Human Genome Project to human health and disease.
- 



#### WHAT is HEALTH and WHAT is DISEASE?

The terms health and disease are frequently used in everyday life, but they are very difficult to define and measure as people have different perceptions or ideas of what the terms mean.

The World Health Organisation (WHO) definition of health is: “a state of complete physical, mental and social well-being which is more than just the absence of disease.” According to this definition, health is not simply the opposite of having a disease. It also includes a mental (psychological) component and a social component which relate to the quality of life, for example whether a person feels happy and fulfilled, in family, work and social life.

A disease is something which disrupts normal bodily functions and typically makes a person feel ill, unwell or unhealthy. Diseases may be **acute**, occurring suddenly and often only lasting for a short period of time, or **chronic**, coming on gradually and lasting for a long period of time. Individual diseases are typically characterised by specific symptoms which a patient can detect, and signs which can be interpreted by health professionals such as doctors, nurses, physiotherapists and psychologists.

#### ◆ CHECKPOINT SUMMARY

- ◆ The terms health and disease are commonly used but poorly understood and impossible to measure. They are also subjective.
- ◆ The WHO suggests a definition of health which includes physical, mental and social components.
- ◆ Health is not simply the opposite of having a definable disease.
- ◆ A disease disrupts the normal functioning of the body. This could include mental and/or physical functioning.
- ◆ Diseases all have specific signs and symptoms which allow them to be diagnosed.

## CATEGORIES of DISEASE

Diseases may be categorised in various ways. They may be broadly divided into mental or physical diseases, and infectious or non-infectious diseases, with sub-groups of each. Many of the categories of diseases overlap so that a single disease may appear in several categories.

### Physical disease

These affect the body and its functioning in some way. They may affect one specific organ (as in coronary heart disease) or be spread throughout the whole body (as in a malaria infection). They may be temporary or permanent. As shown in the examples below, physical illnesses encompass most of the other categories, including some of the mental illnesses.

### Mental disease

Now more commonly called psychiatric disorders these affect the functioning of the brain or mind. The group covers a wide spectrum of disorders including those associated with degeneration of neurones in the brains of older people leading to loss of memory and other brain faculties as in Alzheimer's disease, as well as diseases such as Schizophrenia which may lead to personality changes in younger people. Such potentially severe disorders which often prevent people from functioning in a socially acceptable manner are known as psychoses. Milder forms of mental illness where strong personality changes do not necessarily occur are termed neuroses. These include depression, and extreme anxiety (including phobias).

In the past, and indeed to some extent in the present day, mental diseases have often not received the same recognition as physical diseases in society or within the medical profession. It is, however, becoming apparent that many of these disorders are actually caused by physical changes in chemical messengers or electrical signals within the brain, which can sometimes be treated using drugs in the same way as physical diseases of the body. For example, some forms of depression caused by low levels of certain neurotransmitters in the brain can be treated using drugs which help to restore the levels of such chemicals to normal.

It is thought that some psychoses, including Schizophrenia, have a genetic component as well as a range of social, psychological and environmental components. Some also have an infectious cause: syphilis, for example, was once an important cause of severe mental illness.

### Social diseases

These are a very broad category which may extend to all diseases which are influenced by people's living conditions and social interactions. In particular it includes diseases which have different distributions between different socio-economic classes. Thus it includes diseases such as TB which are made worse by poverty and overcrowding; diseases such as obesity and coronary heart disease which are most common in the lower socio-economic classes of the developed world, and diseases associated with alcohol and drug

misuse which again occur more commonly in specific sectors of society. The term 'social disease' could however be extended to include all diseases spread by social contact, and thus cover the sexually transmitted diseases such as gonorrhoea and a range of other infectious diseases.

**Infectious diseases**

These are caused by specific **pathogens** invading the body. Pathogens are organisms which cause disease and are most commonly bacteria, viruses, and fungi, although they may be single celled animals (e.g. Protoctista), worms or arthropods. Some examples of infectious diseases are HIV/AIDS (caused by a virus) malaria (caused by a protoctistan parasite) and TB and cholera (both caused by bacteria). All infectious diseases can be transmitted (passed on) from one person to another in some way. Infectious diseases may be transmitted via droplets of moisture in the air, through contact including sexual contact where body fluids from one partner enter the tissues of another, via vectors such as mosquitoes, and via infected food or water.

**Non-infectious diseases**

These are not caused by pathogens, but by other factors, such as those in the environment or in the genetic makeup of a person (inherited diseases). There are many different categories of non-infectious diseases including **deficiency diseases**, such as xerophthalmia caused by a deficiency of vitamin A, **degenerative diseases** such as coronary heart disease, **inherited diseases** such as cystic fibrosis, and **self inflicted diseases** such as lung cancer. Mental illnesses are also included in this category.

**Degenerative**

These appear in older people as the body begins to function less efficiently and repair mechanisms fail. They often develop over a long period of time and are often 'multifactorial' (have many contributing causes or factors leading to their development). They include osteoarthritis, caused by ageing of joints and bone tissue; some types of cancer; and coronary heart disease, caused by gradual narrowing of the coronary arteries as fatty deposits accumulate in them, limiting blood flow to the heart muscle. The risk of some of these degenerative diseases, especially coronary heart disease (CHD) and some cancers is increased by long term exposure to certain environmental factors. In the case of CHD these include high fat diets, smoking and lack of exercise. Genetic factors are also believed to increase the susceptibility of some individuals to CHD and some cancers.

**Inherited**

Alternatively known as **genetic diseases**, these are caused by mutations in the genetic material of an individual. Such diseases are passed from parent to offspring at the moment of conception having either been present in the parent or having arisen as new mutations during the production of sex cells (gametes) by the parents. Some diseases in this category arise from chromosome mutations, where individuals have too many or too few



chromosomes due to unequal meiotic divisions. An example is Down syndrome, where an extra copy of chromosome 21 affects a range of mental and physical functions in sufferers. More commonly, however, genetic diseases arise from single gene mutations, where the mutation prevents the production of a normal form of polypeptide or protein in the cells of the affected individual. This in turn can have a direct effect on the mental or physical functioning of the body. Examples are cystic fibrosis, where a gene mutation results in excess mucus production in the lungs, and haemophilia where a gene for the production of a blood clotting factor (most commonly factor VIII) is faulty.

Most inherited diseases caused by gene mutations are **recessive**, so an individual requires two identical copies of a gene before they suffer the disease. This means that healthy individuals may 'carry' genes (recessive alleles) for inherited diseases such as cystic fibrosis without showing any symptoms.

**Self-inflicted**

These result from behaviour known to carry a health risk. They include diseases resulting from smoking (such as lung cancer) where the health consequences are now clearly known, skin cancers resulting from sunbathing without protection when the dangers of UV light are known, and deliberate attempts to harm the body through drug overdose or physical injury.

This category is not well defined, and the inclusion of diseases here is fraught with difficulties.

**Deficiency**

Deficiency diseases are caused by a deficiency or lack of nutrients in the diet. This may be a lack of a major nutrient such as protein, or a lack of a specific micronutrient (vitamin or mineral). Examples of specific micronutrient deficiencies include scurvy caused by a lack of vitamin C, anaemia caused by a lack of iron, and rickets caused by a lack of vitamin D when there is insufficient exposure of the skin to sunlight.

**STUDYING DISEASE: HEALTH STATISTICS**

In order to put in place measures to prevent, control, treat or study disease of any kind it is vitally important to have statistical information about the disease. The collection and study of such statistics relating to patterns of disease is known as **epidemiology**.

At a basic level health statistics may give information on overall death rates in a country and allow the calculation of figures for infant mortality and life expectancy, two major indicators of the health of a population. They will generally also examine the overall number of cases of illness (**morbidity**) and death (**mortality**) from a particular disease in one year. Information from different years may be compared to show whether rates of illness or death from certain diseases are increasing, decreasing or staying at the same level over a period of time.

Usually, however, epidemiologists collect much more detailed information than simply the number of cases of a disease. This

◆ CHECKPOINT SUMMARY

◆ Diseases can be categorised in different ways.

◆ The groupings are not mutually exclusive, so one disease may be considered in several groups.

◆ Broad categorisation splits diseases into physical or mental (psychiatric) diseases or infectious and non-infectious diseases.

◆ Narrower categories recognise social, degenerative, inherited, self inflicted and deficiency diseases.

allows them to study the disease more carefully and to set up specific disease prevention or control programmes aimed at particular target groups in the population. If a disease only occurs, for example, in older people, it is unnecessary to target the whole population. Statistical information is also essential in determining whether certain drugs, vaccinations or treatments have been effective.

Statistical studies of health data can allow **associations** between diseases and certain factors, (often known as **risk factors**) to be established. Whilst this does not actually explain the links, it can form the starting point for further research. The work of Sir Richard Doll which began in the 1950s allowed the strong statistical link between cigarette smoking and lung cancer to be established. This then led to appropriate advice being given to smokers about the risks involved, and has stimulated much research into the processes by which smoking actually causes cancers and other diseases. As with all important studies of disease this was based on the collection of very **large amounts of data** and the use of specific **statistical tests** to interpret the data.

In general the larger the data-set the greater the validity of statistical tests as applied to epidemiological information, yet the exact nature of the data collected will vary between studies. In Doll's study a group of 40 000 men were split into groups on the basis of smoking habits. Deaths from all causes as well as from lung cancer and other respiratory diseases were recorded after 10, 20 and 40 years. This is a form of **longitudinal study** as the same individuals are studied over many years. In contrast a **cross sectional study** will collect data on a large number of individuals at one point in time.

In gathering health statistics for study, epidemiologists must structure their data collection around certain key questions. Some of these include:

- ▼ Is the disease increasing, decreasing or remaining stable over a given time period.
- ▼ What is the age distribution of the disease: is it more common in babies, children, teenagers, adults or the elderly?
- ▼ What is the sex distribution of the disease: is it more common in males or females?
- ▼ What is the geographical distribution of the disease: is it more common in towns or cities and in some regions compared to others?
- ▼ What is the distribution of the disease in relation to social class: is it more common in the richer or the poorer people?
- ▼ What is the distribution of the disease in relation to occupation: is it linked to particular types of work?

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◆ CHECKPOINT SUMMARY

◆ The collection and study of disease/health statistics is known as epidemiology.

◆ Health statistics are essential to disease treatment and prevention programmes.

◆ Basic health statistics used to assess the overall health of a population include life expectancy and infant mortality rate.

◆ The number of cases of morbidity and mortality for individual diseases are also collected.

◆ Data can be used to establish associations between certain diseases and risk factors: e.g. between smoking and lung cancer. This may lead to research into the causes of the disease.

◆ Generally very large amounts of statistical data must be collected, in carefully defined studies and analysed using appropriate tests.

◆ Epidemiologists gathering data on a disease may consider the effects of factors such as age, sex, socio-economic group, occupation, geographical location on the disease.

## HEALTH STANDARDS in the DEVELOPED and DEVELOPING WORLD

The types of diseases described above are not distributed evenly across the world. There are different patterns of disease in developing and developed countries as well as differences in the overall standards of health, which reflect biological, social and economic factors. (Enormous differences in disease experience do however exist between high and low income groups within both developed and developing countries). Broadly speaking, standards of health as measured by rates of infant mortality and life expectancy are lower in most developing countries compared to developed countries. It must, however, be borne in mind that these figures give only a crude measure of health and do not, of course, take into consideration quality of life, which is much more difficult to measure.

### Developed world

If measures of infant mortality rate (number of deaths per 1000 live births amongst children aged 0-1 year) and life expectancy are used as indicators of health then most developed countries show high standards of health. In the U.K, life expectancy for women is now 80 years and for men 75 years. Infant mortality stands at under 10 deaths per 1000 births.

The main causes of illness and death in the developed world are non-infectious degenerative diseases, especially coronary heart disease, cancers, and illnesses related to smoking and alcohol. Some infectious diseases, which were the major causes of death until the mid twentieth century, still cause illness and some deaths but their importance is vastly reduced. Some infectious diseases like TB and HIV/AIDS are, however, causing increasing numbers of deaths in many developed countries. Although more difficult to measure, mental disorders, especially depression, self inflicted diseases often related to the misuse of alcohol and other drugs, and stress are all increasing. This suggests that overall health and quality of life for many people in developed countries is not as high as could be expected.

The dramatic decline in deaths from infectious disease and consequent rise in conventional standards of health in developed countries can be explained by a complex of factors experienced over the past century. These primarily include improvements in sanitation and living conditions, nutrition, education and medical care, including the availability of vaccines and antibiotics. It is worth noting that in 1910, before most of these changes were in place, life expectancy for English men was 49 years and for women 53.

Health improvements have also relied upon sustained economic growth, stability of government, reductions in birth rates (partly through availability of contraception) and the establishment, in some countries, of National Health Services offering free medical care.

### Developing countries

In many developing countries there are very low standards of health. The infant mortality rate in some sub-Saharan African countries exceeds 200 deaths per 1000 births. Life expectancy of people in the same regions may be as low as 45 years. (In some southern African

#### ◆ SPECIAL SUMMARY A

*The terms developed and developing countries are frequently used to refer to high and low income regions of the world even though they are unsatisfactory terms in many respects. A developed country is generally characterised by most or all of the following features: a relatively high Gross Domestic Product (GDP), a high level of industrialisation and urbanisation, a relatively low proportion of the population engaged in agricultural work, a stable population, a high life expectancy, a low birth rate, a low infant mortality rate, relatively high standards of health and a high level of literacy. In contrast developing countries have the reverse of most of these features. It should, however, be stressed that such features will vary widely between different geographical regions of a given country and between different socio-economic groups within a country. Thus regions of some developing countries show features of developed countries and vice versa. For the purposes of this chapter developing countries will be taken to include most of Africa, Asia, South and Central America, parts of Asiatic Russia and the Pacific Islands. Developed countries primarily include Western Europe, The United States, Australia and New Zealand.*

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countries e.g. Zimbabwe current life expectancies of 59 years are expected to decline to 45 as HIV/AIDS kills increasing numbers of young adults). In the poorest developing countries, including most African countries, infectious diseases are the most important causes of illness and death. Respiratory infections, HIV/AIDS, diarrhoeal diseases, TB, malaria and a range of diseases associated with childbirth are the main killers. Nutritional disorders e.g. protein-energy malnutrition, anaemia and vitamin A deficiency are also common. The impact of non-infectious diseases must not, however, be overlooked. These are already the leading cause of death in many developing countries where deaths from cardiovascular disorders, smoking related illnesses and cancers are increasing rapidly. This is particularly true amongst higher income urban groups in developing countries.

The reasons why standards of health are so low in parts of the developing world are highly variable between regions, and relate mainly to social, economic and political conditions rather than geographical or biological factors. Any or all of the following factors may have a significant impact on health standards in developing countries.

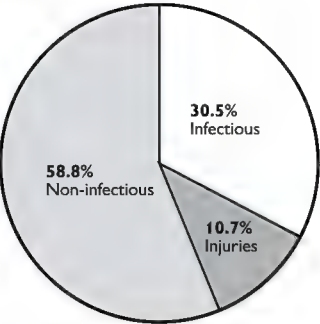
- ▼ A lack of basic sanitation (provision of clean water and toilet facilities) coupled with overcrowded conditions, particularly in large cities, encourage the spread of infectious diseases.
- ▼ Poor nutrition which may depress the immune system and increase the risk of infections.
- ▼ Insufficient medical facilities, including a lack of qualified doctors and nurses, medicines, and other essential medical equipment. These circumstances are made worse by the fact that many regions of the developing world are remote and inaccessible and transport facilities may be limited.
- ▼ A lack of basic education about hygiene and nutrition may increase the risk of some infectious and deficiency diseases
- ▼ High birth rates and inadequate maternal care lead to high rates of infant mortality.
- ▼ Civil unrest, unstable government, poor economic growth and large debts all limit spending on, and organisation of, health services.

◆ CHECKPOINT SUMMARY

- ◆ Biological, social, economic and political factors influence the pattern of diseases found across the world.
- ◆ Using life expectancy and infant mortality rate as indicators, the developed world has, on average, a better overall standard of health than the developing world. Ideally the quality of life also needs to be considered, although it is hard to measure.
- ◆ Developed countries show long life expectancy and low infant mortality. Degenerative diseases account for most deaths. Mental diseases are also a major cause of illness.
- ◆ High standards of health have been achieved in the past century due to improved nutrition, education, health services, economic prosperity and political stability.
- ◆ Developing countries have, on average, lower life expectancy and higher infant mortality. Infectious diseases remain the main cause of death in many countries but degenerative diseases are also becoming very common, especially in urban areas.
- ◆ Poor nutrition, lack of basic sanitation, low levels of education, and insufficient medical facilities, low GDP and geographical isolation are factors in low health standards.

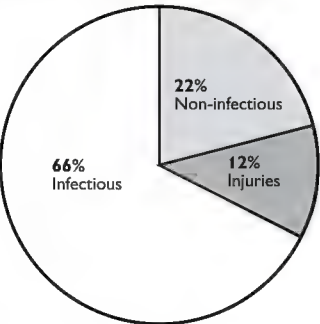
Pattern of disease distribution

Worldwide



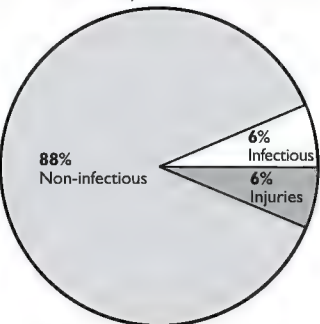
Africa

Including the world's poorest countries



Europe (West)

Including some of the richest developed countries in the world



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## PATTERNS of DISEASE DISTRIBUTION

The types of disease found in different countries are highly variable. Some diseases are always present and cause illness or death of large numbers of people every year. Others are always rare, and still others fluctuate wildly over time, killing many people one year and few in other years. In rare cases diseases can affect millions of people all over the world at the same time. Three broad terms are used to describe these patterns: **endemic**, **epidemic** and **pandemic**. It should be noted that the same diseases may be epidemic, endemic and pandemic at different times and in different regions, and that in epidemiology the use of these terms is usually restricted to infectious diseases.

### Endemic

This is a term used to describe diseases which are common in populations all the time. An example is malaria in East Africa which kills thousands of children every year and shows relatively little variation in numbers of cases from one year to another.

### Epidemics

These are defined as a short-term increase in the national incidence of a disease which is normally absent or occurs at a low level in that population. Regular influenza epidemics, such as the one in the winter of 1999, hit Britain. Cholera epidemics frequently occur during war or famine situations.

### Pandemics

These are epidemics which affect most or all of the world at the same time, such as the influenza pandemic in 1918 which killed several million people worldwide and plague pandemics in the 14th century which killed up to one third of the inhabitants of Europe. There is currently an HIV/AIDS pandemic which is killing over 2.5 million people per year.

#### ◆ CHECKPOINT SUMMARY

- ◆ An endemic disease is one which is always present in a region and causes a similar number of illnesses and deaths every year.
- ◆ Epidemics are defined as short term increases in the national incidence of a disease which normally occurs at much lower levels.
- ◆ Pandemics are epidemics which affect most or all of the world at the same time.
- ◆ The same diseases may be endemic, epidemic or pandemic depending on circumstances.

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## The HUMAN GENOME PROJECT and its ROLE in HUMAN HEALTH and DISEASE

The Human Genome Project is a major initiative in genetics which aims to sequence the entire human genome (the entire genetic code represented by the bases A,C,T and G on all of the DNA of the 23 chromosomes of a single set). A 'rough draft' of the sequence is expected in 2000, with a final version by 2003. Automated techniques and computers have made such a vast project possible; in the past sequencing a single gene was a major undertaking.

The sequencing process will reveal the number of genes present (thought to be about 100 000, made up of 3 billion base pairs), as well as the extent of non-coding DNA that exists. Differences between individuals at the sites of genes and non-coding DNA will also be determined since the DNA of several individuals is being

sequenced for comparison. At present it seems that two given individuals taken at random from anywhere in the world share 99.9% of their DNA base sequence. Yet the 0.1% which is different still represents up to 3 million differences in the nucleotide (base) sequence both in genes and in non-coding DNA. Most of these are in the form of differences in single nucleotides (single nucleotide polymorphisms or SNPs). Some of these are important in influencing observed differences between people: not just in appearance but in their susceptibility to certain diseases. All information on the genome sequence is to be available in the public domain to allow maximum use of the information for research purposes. No gene sequences will be patented by individuals in Europe.

Impressive though the sequencing of 100 000 genes may be, this phase of the Human Genome Project should be considered as a starting point for further research on the function of the genes both in health and in illness. Progress in this field should change the way that many branches of medicine work and play a significant role in the prevention, treatment and cure of a range of diseases. Some of the ways in which such future research stemming from the human genome project may be important, are listed below.

**Identification of genes associated with disease.** Once the genome has been sequenced research into the relative contributions of genetic and environmental factors in disease will be possible on a larger scale than in the past. Comparisons of the DNA sequence of large groups of people with a specific disease, with controls who do not have the disease, should highlight areas of the genome where differences exist and lead researchers to genes which might be involved in the development of the disease.

In some cases a single gene may be found to cause the disease. An analysis of the pathway from faulty gene to faulty protein and disease may reveal details about the workings of cells and organs in the diseased and normal states, and so to the development of new drugs. In other cases several genes may be linked in such a way that the disease is only triggered by a particular combination of genetic and environmental factors. Genes influencing susceptibility to various types of cancer, cardiovascular disease, asthma and diabetes may be discovered, as may genes affecting the severity of certain infectious diseases like malaria, HIV and TB.

**Genetic screening.** If genes affecting disease susceptibility are identified then one of the applications of such research will be to improve genetic screening programmes. Whilst many people worry that the use of such screening in a non-medical setting (for example by insurance companies, or employers) might lead to discrimination against individuals on the basis of their genes there are many potential benefits which could arise from it if it is backed up by suitable genetic counselling. One such benefit is to allow the screening of babies to test for genetic diseases which may be treated or cured before harm can be caused. One current test for the genetic disease PKU detects affected individuals at birth. If these babies are fed special diets they will never suffer the severe mental and physical retardation which would otherwise affect them. Other similarly treatable conditions could be found. Screening of adults may reveal whether an individual is at risk of developing a certain disease such as diabetes or some types of cancer. In such cases doctors may be able to recommend modifications to lifestyle to reduce the risk of actually developing such a disease.

**Gene therapy.** Identification of gene mutations which lead to specific genetic diseases, and of mechanisms involved in switching genes on and off in cells, may stimulate further research into gene therapy. This is a branch of medicine whereby faulty genes in an individual are replaced by delivering the 'normal' form of the gene into target cells. At present such research is in its infancy and is only being trialled in adults (so called somatic gene therapy) rather than in the gametes or early stage embryo (germ line gene therapy) which would change the genes that an individual passes on. The possibility of extending such techniques to manipulate not only disease genes but genes affecting personality, intelligence, appearance and physical performance, is often raised as a negative aspect of the human genome project.

**Tailor made medicines.** One of the major benefits of the Human Genome Project which could be in action within the next 5-10 years is based on the concept of **pharmacogenetics**. This involves using genetic information about a patient to work out which medicines are most likely to be effective in treating their condition. It is based on the observation that there are strong genetic components both to positive drug reactions (situations where drugs work well) and negative drug reactions (side effects). For example, there are already some genes linked to hypertension (high blood pressure) and more are likely to be discovered. There are also over fifty drugs available to treat hypertension, but each patient will respond only to some of these fifty drugs owing to underlying genetic factors responsible for the condition. Using genetic information from the patient (based on variation in base sequence at SNP sites) and information from previous research, the doctor should be able to predict the best drug to use rather than using trial and error. A similar genetic test may indicate individuals at risk of serious side effects in response to vaccinations.

**Genetic engineering.** Human proteins like insulin and factor VIII are already produced in genetically engineered organisms for use in treating human conditions. As the human genome project identifies the location and sequence of genes coding for other essential proteins and recognises diseases resulting from faulty genes, then the use of such techniques is likely to increase. It has been suggested that genes for the production of human milk could be introduced into cows. Other future projects include the genetic manipulation of mammals to allow the production of organs for transplant into humans (xenotransplantation). Even if not identical to human organs these could be tailor-made to display particular human antigens on the surface of cells, thus preventing organ rejection.

◆ CHECKPOINT SUMMARY

- ◆ The Human Genome Project aims to have an accurate sequence of the entire human genome (genes and non-coding DNA) by the end of 2000. This is a starting point for future genetic research.
- ◆ Comparison of DNA from several individuals has so far indicated that all humans share about 99.9% of the DNA base sequence: the 0.1% difference is of great medical interest.
- ◆ The long term significance of the human genome project is enormous. It should allow for identification of disease genes, associated improvements in genetic screening, gene therapy, the rise of pharmacogenetics and advances in genetic engineering.
- ◆ Such advances should thus improve diagnosis, treatment, prevention and cure of a range of diseases with the potential to improve health standards across the world.

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## 2.2.

## Diet

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### Content

- ▼ The concept of the balanced diet
- ▼ Energy and nutrient requirements
- ▼ Essential nutrients
- ▼ The consequences of malnutrition
- ▼ Diet and coronary heart disease

Candidates should be able to:

- a) list the components of a balanced diet.
- b) discuss the energy and nutrient requirements of people with reference to gender, age, activity, pregnancy and lactation.
- c) explain what is meant by the term dietary reference value (DRV) and describe how these values should be used.
- d) describe the functions of essential amino acids, essential fatty acids and vitamins A and D in the body.
- e) describe the consequences of malnutrition with reference to energy and protein deficiency, anorexia nervosa, deficiencies of vitamins A and D, and obesity.
- f) discuss the possible links between diet and coronary heart disease.

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### The BALANCED DIET

Although population groups show enormous variations in diets across the world one essential feature of human diets is the need for a relatively diverse range of foods to supply the required range of nutrients.

In order to grow and develop, maintain health, and perform various activities efficiently, the body requires the correct nutrients, in the correct amounts, on a regular basis. A diet that provides this is known as a **balanced diet** since it contains a balance of nutrients from the main food groups. The macronutrients: carbohydrates, proteins and fats, which are needed in relatively large amounts, and the micronutrients: vitamins and minerals which are needed in very small amounts. Water, is also an essential component of the diet although is not usually regarded as a nutrient. Dietary fibre (roughage or Non Starch Polysaccharides (NSP) is also an essential dietary component even though it provides no nutritional value.

Each of these nutrients, along with water and fibre has an essential role in the body, and a deficiency may result in specific disease symptoms which may be fatal. Broadly speaking the functions of these groups are as follows:



**Carbohydrates and fats** provide energy for the body as they are respired by cells to generate ATP for muscular contraction, cell division and growth, and to generate heat to maintain body temperature. Excess carbohydrates and fats are converted to fats in the body and used as a long-term energy store.

**Proteins** are required for growth and repair of cells. As discussed later, their constituent amino acids are used to produce all of the proteins required in the body, including hormones, enzymes, antibodies etc. They may also be used as an energy source in respiration but in most circumstances provide less than 20% of total energy. In starvation conditions or where a diet is high in protein but low in carbohydrates and fats, they can be a major energy source.

**Vitamins** are organic compounds with a wide range of functions in the body which include acting as enzyme co-factors (many of the B vitamins) and controlling many metabolic processes in cells. Some are water soluble (B vitamins, vitamin C) and cannot be stored in the body, whilst others (e.g. vitamins A and D) are fat soluble and may be stored in the liver.

**Minerals** are inorganic dietary components and, like vitamins, have a wide range of essential functions. Some are required for the formation of major chemicals in the body e.g. phosphorus for ATP, and iron for haemoglobin. Sodium and potassium are vital for electrical conductivity in neurones and calcium in the formation of hard bones and teeth. Calcium is also important in muscle contraction. Minerals needed in particularly small amounts are called trace elements e.g. cobalt used in vitamin B12.

**Fibre** is basically cellulose and related polysaccharides from plant cell walls which cannot be digested by humans. Fibre promotes the proper working of the digestive system since its bulk helps to satisfy the appetite, at the same time as aiding the movement of food through the gut by peristalsis. The transit time of food through the gut is thus reduced, which may prevent the accumulation of harmful putrefactive bacteria and consequent gut disorders including, perhaps, some cancers of the large intestine.

**Water** comprises 60-75% of the body weight and is essential for almost all cell functions. It forms the basis of blood and the cytoplasm of cells. An adult human cannot normally survive more than a few days without water.

The balance of the diet is important as there are many complex interactions between different foods which affect their absorption and use in the body. For example, the presence of cellulose fibres and phytic acid (found in wholemeal bread) decreases the uptake of available calcium, zinc, and iron, whereas calcium uptake is increased by vitamins D and C. A range of food types of animal and plant origin should also help to ensure that essential amino acids and fatty acids are consumed in the correct proportions. Some nutrients can be stored in the body so regular intake is less crucial whilst others cannot be stored so need to be taken more regularly to ensure optimum levels in the body.

#### ◆ CHECKPOINT SUMMARY

- ◆ Populations show enormous variation in diets across the world, but all require the same basic nutrients.
- ◆ A balanced diet provides the correct nutrients, in the correct amounts, on a regular basis.
- ◆ Macronutrients: carbohydrates, fats, and proteins are needed in relatively large amounts.
- ◆ Micronutrients: vitamins and minerals are needed in relatively small amounts.
- ◆ Water and dietary fibre are essential components of the diet although not regarded as nutrients.
- ◆ Carbohydrates and fats supply energy.
- ◆ Proteins supply amino acids for growth and repair. Some of which are essential and must be supplied in the diet. Non-essential amino acids can be interconverted within the body from essential amino acids.
- ◆ Vitamins are essential organic compounds that must be supplied in the diet and are involved in all aspects of metabolism.
- ◆ Minerals are essential inorganic substances which have a wide range of metabolic and structural functions.
- ◆ Water is essential for all life processes.
- ◆ Fibre provides bulk to the diet for efficient movement of the food through the gut by peristalsis.
- ◆ Balance of nutrients is important due to complex interactions between their digestion and absorption in the gut.

## ENERGY and NUTRIENT REQUIREMENTS

The energy and nutrient needs of an individual vary according to a number of factors. These can be considered in absolute terms (the total amount of a nutrient required by an individual) or in relative terms (the amount required per kg. of body mass). The main factors which influence requirements are: body size, gender, activity levels, age, pregnancy and lactation. These factors are discussed in more detail later.

### Energy requirements

Energy intake from carbohydrates and fats is measured in Kilojoules (kJ), megajoules (MJ) or kilo calories (kcal). A kilojoule is one thousand joules, and a megajoule one million joules. A calorie is equivalent to 4.18 joules and a kilocalorie (often written Calorie with a capital C as seen on food labels) is one thousand calories.

The amount of energy required by a person per kg of body mass is dependent on two main factors: their **basal metabolic rate (BMR)** and their **activity level**.

**BMR** is a measure of the energy used for vital functions (neural, cardiovascular, respiratory, excretory etc) whilst the body is at complete rest in a thermoneutral environment (one in equilibrium with the body temperature). This value ranges from around 200-400 kJ/hr in adults. Variation between adults is explained by differences in body size, body composition (muscle cells have higher energy requirements than fat cells) and cellular activity associated with growth.

**Activity levels** may be expressed as **multiples of BMR**. A sedentary person (such as an office worker) would use only 1.4 times more energy than BMR, whilst an active one (such as an athlete) may use at least 3 times more energy than BMR.

The figures quoted below show **Estimated Average Requirements (EARS)** of energy for people of different ages and sexes. This figure is obtained by multiplying the BMR by the average physical activity level of an individual of that age. An activity level of 1.4 times BMR is used to reflect the sedentary lifestyle of most people in the UK.

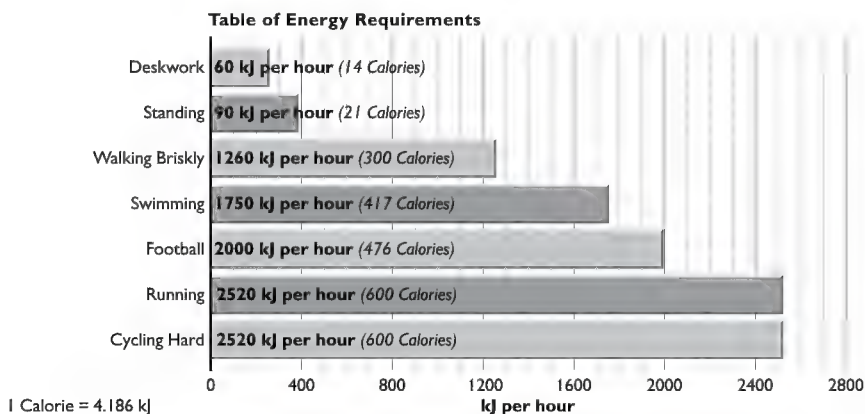


Table of energy requirements by age and sex

| Estimated Average Requirements (EARs)<br>for Energy in the UK (per day) |               |             |
|-------------------------------------------------------------------------|---------------|-------------|
| Age range                                                               | EARs          |             |
|                                                                         | MJ/d (kcal/d) |             |
|                                                                         | Males         | Females     |
| 0 - 3 months                                                            | 2.28 (545)    | 2.16 (515)  |
| 4 - 6 months                                                            | 2.89 (690)    | 2.69 (645)  |
| 7 - 9 months                                                            | 3.44 (825)    | 3.20 (765)  |
| 10 - 12 months                                                          | 3.85 (920)    | 3.61 (865)  |
| 1 - 3 years                                                             | 5.15 (1230)   | 4.86 (1165) |
| 4 - 6 years                                                             | 7.16 (1715)   | 6.46 (1545) |
| 7 - 10 years                                                            | 8.24 (1970)   | 7.28 (1740) |
| 11 - 14 years                                                           | 9.27 (2220)   | 7.72 (1845) |
| 15 - 18 years                                                           | 11.51 (2755)  | 8.83 (2110) |
| 19 - 50 years                                                           | 10.60 (2550)  | 8.10 (1940) |
| 51 - 59 years                                                           | 10.60 (2550)  | 8.00 (1900) |
| 60 - 64 years                                                           | 9.93 (2380)   | 7.99 (1900) |
| 65 - 74 years                                                           | 9.71 (2330)   | 7.96 (1900) |
| 75+ years                                                               | 8.77 (2100)   | 7.61 (1810) |
| Pregnancy                                                               | +0.80* (200)  |             |
| Lactation:                                                              |               |             |
| 1 month                                                                 | +1.90 (450)   |             |
| 2 months                                                                | +2.20 (530)   |             |
| 3 months                                                                | +2.40 (570)   |             |
| 4-6 months                                                              | +2.20 (525)   |             |
| >6 months                                                               | +1.65 (395)   |             |

\*last trimester only. NB 1MJ = 1 megajoule. Activity based on sedentary life style (1.4 x BMR)

From Manual of Nutrition, Reference Book 342 (HMSO) 10th ed (1995)

As seen in the table, patterns of absolute energy requirement show that the larger an individual is (in terms of body mass and or height) the greater his or her energy requirement. Thus the adult man, who is on average larger than the adult woman, has a higher proportion of metabolically active cells (more muscle cells compared to fat cells), a larger heart and organs, and a higher requirement for energy. His absolute requirement will of course vary with his level of energy expenditure: the average value of 10.6 MJ or 2550 kcal for a sedentary man (1.4 x BMR) may increase to 22.7 MJ or 5464 kcal. for a highly active man (3 x BMR). A highly active woman might require 17.4 MJ compared to 8.1 MJ if sedentary. With increasing age, the daily energy requirements in both men and women decrease by up to 800kJ (200 kcals), as a result of a decrease in muscle mass, a drop in metabolic rate, and usually a decrease in activity.

If energy requirements per kg body weight are used, then young babies and children of both sexes will be seen to have the highest relative energy requirements. This reflects the fact that children are growing rapidly and growth requires energy for the synthesis of new cells and tissues creating a higher BMR. The BMR of a baby or young child may

be over twice that of an adult. A further factor is the surface area to volume ratio, which decreases with increasing size. Heat energy is lost over the surface area of the body, and the larger the surface area in relation to the volume of the body, the greater the metabolic rate required to maintain body temperature. Children over 1 year also tend to be highly active, again raising energy requirements. Adolescents, especially boys, also show high requirements due to rapid growth.

During pregnancy extra energy demands are made by the formation of the fetus and the placenta, the development of the uterus, an increase in blood volume, and an increase in storage of fat. However, a decrease in activity towards the end of the pregnancy counters this increase in BMR, so that overall there is only a slight increase in energy demand of about 0.8MJ (200 kcal) per day. The production of milk (lactation) puts a highly variable demand on the mother's food resources, but an average figure for the increased energy demands of milk production is about 2.1 MJ (500 kcal) per day.

Any individual recovering from illness or injury has a higher requirement for both protein and energy. This may allow missed growth to be 'caught up' or to allow damaged tissues (such as burns, broken bones) to be repaired. Individuals exposed to cold conditions for long periods during the day and/or night will also have a higher energy requirement than those in warmer conditions since the body uses extra energy to maintain a constant body temperature.

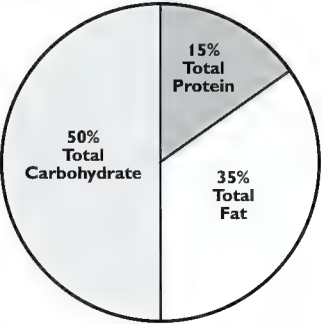
**Nutrient requirements**

Protein demand, relative to body mass, is highest in babies and young children with an additional peak at adolescence since protein is required for growth. In pregnant women an increase in the requirement for protein of about 6 g per day, is needed for the development of the new tissues described above. In lactating women there is also an increase in the requirement for protein of about 11 g per day, which is needed for the synthesis of milk protein. In other adults the requirement per kg body weight is slightly higher in men than women owing to greater amounts of muscle tissue. Some athletes may have an increased protein requirement but this is usually supplied along with the overall increase in energy intake. In general, individuals in developed countries eat more protein than required. It is thought that the body can adapt to low protein levels by using proteins more efficiently, which could explain why many people in the developing world exist on protein levels well below the Recommended Nutrient Intakes (RNIs) of the developed world.

Vitamin and mineral requirements are higher per kg body mass in infants and children compared to adults, as new body tissue is being synthesised. Vitamin D and calcium requirements are very closely linked to growth periods due to their roles in bone formation. The requirements for Vitamin D, Vitamin A, calcium, iron and folic acid are significantly increased during pregnancy as new fetal tissues including bones, blood and muscles are being formed. They also continue to be required at above normal levels during lactation so that milk with adequate nutrients is provided for growth of the baby.

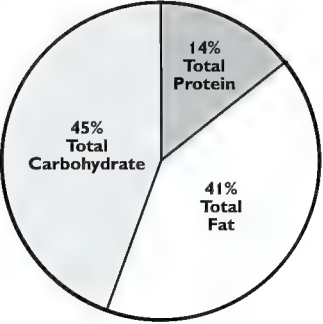
In general, women from puberty to menopause, have a higher requirement for iron to make up for the monthly losses through menstruation. Iron deficiency leading to anaemia is extremely common in women in the developing world, and is also relatively frequent in developed countries.

**Suggested energy mix in UK diet 1993**  
(excluding alcohol)



**Total Fat**  
saturated fatty acids 11%  
monounsaturated fatty acids 13%  
polyunsaturated fatty acids 6.5%

**Actual energy mix in UK diet 1993**  
(excluding alcohol)



**Total Fat**  
saturated fatty acids 16.1%  
monounsaturated fatty acids 15.2%  
polyunsaturated fatty acids 6.9%

## DIETARY REFERENCE VALUES (DRVS) and their USE

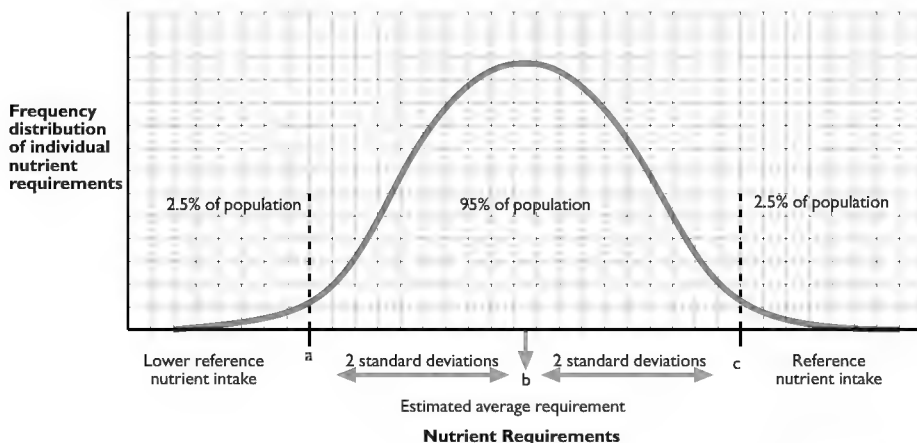
Individual variation in size, body composition and other factors means that it is impossible to give exact recommendations for the nutrient intake of a given individual. Instead population guidelines known as Dietary Reference Values (DRVs) have been established based on various measures of the range of requirements for each nutrient within a population, which are assumed to be normally distributed. Such figures, produced in 1991 by the Committee on Medical Aspects of Food Policy (COMA), are used by the government and other bodies to advise on food policy. Figures are given for each age group and both sexes within a population.

**Estimated Average Requirement (EAR)** of energy or protein, a vitamin or mineral. This is particularly used with reference to **energy**. 50% of the population in a given age/sex group will require more than the EAR and 50% less.

**Reference Nutrient Intake (RNI).** This figure for protein, minerals and vitamins represents the intake which is adequate for more than 97% of the population (2 standard deviations above the EAR). Thus if a group has an average intake at or above the RNI level it can be assumed that no-one will be deficient in that nutrient. The RNI for a group can indeed be set at the upper end of the range of requirements, as an intake moderately in excess of requirements (for protein, vitamins and minerals) has no adverse effects, but reduces the risk of deficiency. (The RNI was previously called the recommended dietary allowance (RDA).

**Lower Reference Nutrient Intake (LRNI)** for protein, or a vitamin or mineral is a level 2 standard deviations below the EAR. Such a level is enough for only the few people (2.5%) in a group who have naturally low needs. Intakes below this level are almost certainly inadequate for most in the population over a period of time, and an average intake in a group around the LRNI would indicate that most people would be suffering a deficiency.

**Safe Intake (SI)** is the range of intakes of a nutrient for which there is not enough information to estimate EAR, RNI, or LRNI. Safe intakes are given for some of the trace elements.



It should be noted that there is no RNI or LNRI for energy because excess intake leads to obesity and increases the risk of cardiovascular disease. Very low intakes can also be harmful. For this reason recommendations for energy have been set as the average of energy requirements. Further recommendations by COMA in 1991 refer to the percentage of energy intake that should come from carbohydrates and fats respectively. In 1990 40% of the daily energy intake of a British adult came from fat and 40% from carbohydrate. Recommended levels are 33% from fat and 47% from carbohydrates. Within this there are recommendations for low levels of saturated fats and refined sugars compared to unsaturated fats and starches. Most of the remainder will come from proteins (up to 20 per cent of the daily energy requirements).

## Uses of Dietary Reference Values

There are several uses of Dietary Reference Values.

**Dietary planning.** Although DRVs are not suitable for judging whether an existing diet is suitable for an individual they can be used to plan a diet for a person or group of people in an institution (such as a boarding school or hospital). If RNIs are followed for protein, minerals and vitamins, very few deficiencies should occur. Pregnant women are examples of individuals who might be advised to ensure that they meet the RNI for folic acid, calcium and other nutrients. Patients with mild anaemia would be encouraged to meet the RNI for iron. Planning energy intake is much more difficult.

**Assessing diets** (of groups). Assessing the levels of nutrient intake in a population and comparing them to DRVs can give information about possible nutrient deficiencies in that population. This may lead to specific interventions. A large number of studies in developing countries have indicated low intakes of protein and energy in groups of children and pregnant women, leading to supplementation programmes.

**Labelling of food products.** Many processed foods carry nutritional information on the packets to allow individuals to gauge their nutritional value. Most breakfast cereals will quote the percentage of **recommended daily intake** (RDI) of a range of minerals and vitamins which would be provided by a standard serving. Most still use the term RDA although COMA suggests that they use figures based on Estimated Average Requirement. Energy requirements are not quoted although levels of energy per 100g are often given as a percentage of energy from fat (saturated and unsaturated) and carbohydrate. Knowledge of RNIs may also allow the manufacturers to add appropriate levels of vitamins and minerals to their products.

**Agriculture and economics.** On a larger scale, DRVs can be used to make predictions about food requirements for whole countries or regions and so influence agricultural and economic policies. Previous versions of nutrient requirements were used by the British Government to plan food policy (including rationing) during the Second World War.

### ◆ CHECKPOINT SUMMARY

- ◆ Energy and nutrient requirements vary with gender, age, activity, pregnancy and lactation.
- ◆ Males are generally larger than females and have a greater proportion of muscle, and thus a greater metabolic rate.
- ◆ Metabolic rate and activity fall with age, often resulting in gain in body mass.
- ◆ Activity levels may be expressed as multiples of the Basal Metabolic Rate (the BMR at rest).
- ◆ Energy requirements are expressed as Estimated Average Requirements (EARs) obtained by multiplying the BMR by the average physical activity level of an individual of a particular age group.
- ◆ Dietary Reference Values (DRVs) are based on the range of requirements for each nutrient within a population, which is assumed to be normally distributed.
- ◆ Estimated Average Requirements (EAR) will satisfy the requirements for half the population in a given group.
- ◆ Reference Nutrient Intake (RNI) will satisfy the requirement for protein, minerals, and vitamins for more than 97% of a given population.
- ◆ Lower Reference Nutrient Intake (LRNI) for protein, minerals, and vitamins are sufficient for only 2.5% of a given population.
- ◆ Safe Intakes are estimated where there is not enough information to derive EARs, RNIs, or LNRIIs
- ◆ RNIs and LNRIIs are not given for energy requirements.

## FUNCTIONS of ESSENTIAL NUTRIENTS

In a literal sense all nutrients are essential, but nutritionists use the term 'essential nutrient' to refer to those which must be present in the diet for the maintenance of health. 'Non-essential nutrients', need not be present in the diet because their lack can be compensated for by the metabolism of the body. For example the lack of sugars in the diet is compensated for by sugars provided by the digestion of starch.

### Essential amino acids

Whilst each of the twenty amino acids has its own specific function, only 8 of these are required in the diet of an adult (10 in a child) as they cannot be made in the body, or made in sufficient quantities to meet requirements. These are the **essential amino acids** and include phenylalanine, valine, tryptophan, threonine, lysine, leucine, isoleucine, and methionine. The other 12 (**non-essential amino acids**) can be synthesised in the liver by the process of transamination (transferring amino groups between molecules).

Proteins which contain all of the essential amino acids are known as **proteins of high biological value** (previously first class proteins). These include many animal proteins including meats and dairy products as well as some plant proteins such as soya. Proteins from most plant sources do not, however, yield the full range of essential amino acids in sufficient amounts. Therefore they are known as second class proteins or **proteins of low biological value**. A balanced mixture of plant proteins can, however, yield a full range of essential amino acids in sufficient quantities.

### Essential fatty acids

Fatty acids are derived from polyunsaturated fats in the diet. Whilst fats are primarily associated with energy supply, the fatty acid components have numerous other roles within the body. Of the many types of fatty acids, two are known as **essential fatty acids**. These can be found in most plant-derived oils and are capable of being stored in the body, therefore deficiencies are rare.

Many functions are associated with these two essential fatty acids. As well as being involved in the formation of phospholipids, the main component of the cell membrane, they are also thought to play a regulatory role in the transport and processing of cholesterol in the body. This is very important as cholesterol is required for the production of vitamin D and some hormones. Linolenic acid is required for development of the brain and retina and may also play a role in reducing the risk of blood clotting within arteries.

### Vitamins

These are a group of unrelated organic chemicals which are extremely important in promoting and maintaining normal growth, development, reproduction and general health. Without them specific deficiency symptoms occur which may seriously threaten health. It is, however, difficult to assess the exact amount of vitamins required in a diet. Two examples of vitamins whose roles are relatively well understood are vitamins A and D.

Figure 1 consists of 10 horizontal bar charts, each representing a different category. The categories are labeled on the left: 1. 100%, 2. 100%, 3. 100%, 4. 100%, 5. 100%, 6. 100%, 7. 100%, 8. 100%, 9. 100%, 10. 100%. Each chart has a horizontal axis with a scale from 0 to 100. The bars are colored in a light blue shade. The data for each category is as follows:

| Category | Percentage |
|----------|------------|
| 1. 100%  | 100%       |
| 2. 100%  | 100%       |
| 3. 100%  | 100%       |
| 4. 100%  | 100%       |
| 5. 100%  | 100%       |
| 6. 100%  | 100%       |
| 7. 100%  | 100%       |
| 8. 100%  | 100%       |
| 9. 100%  | 100%       |
| 10. 100% | 100%       |

1. \_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_

4. \_\_\_\_\_

5. \_\_\_\_\_

6. \_\_\_\_\_

7. \_\_\_\_\_

8. \_\_\_\_\_

9. \_\_\_\_\_

10. \_\_\_\_\_

1. *What is the main purpose of the study?*

2. *What are the research questions or hypotheses?*

3. *What methods were used to collect data?*

[illegible]

### ◆ CHECKPOINT SUMMARY

- ◆ Essential nutrients are those which must be present in the diet for the maintenance of health.
- ◆ 8 amino acids are essential in adults (10 in children), the other 12 (10 in children) amino acids can be synthesised in the liver from the essential amino acids.
- ◆ Proteins containing all the essential amino acids are known as 'proteins of high biological value'.
- ◆ There are two essential fatty acids, both of which are polyunsaturated.
- ◆ Vitamin A (retinol) is essential for the visual pigment rhodopsin in the retina, for healthy skin and epithelia, and growth and bone formation in children. Excess can be toxic.
- ◆ Vitamin D or calciferol is found especially in eggs, dairy products, and some oily fish; but is also formed by the action of UV light on the skin. It is essential for strong bones and teeth. Excess can be toxic.



### Reference Nutrient Intakes for Vitamins

| Age               | Vitamin C | Vitamin A | Vitamin D |
|-------------------|-----------|-----------|-----------|
|                   | mg/day    | mg/day    | mg/day    |
| 0-3 months        | 25        | 350       | 8.5       |
| 4-6 months        | 25        | 350       | 8.5       |
| 7-9 months        | 25        | 350       | 7.0       |
| 10-12 months      | 25        | 350       | 7.0       |
| 1-3 years         | 30        | 400       | 7.0       |
| 4-6 years         | 30        | 400       | -         |
| 7-10 years        | 30        | 500       | -         |
| <b>Males</b>      |           |           |           |
| 11-14 years       | 35        | 600       | -         |
| 15-18 years       | 40        | 700       | -         |
| 19-65 years       | 40        | 700       | -         |
| 65+ years         | 40        | 700       | 10.0      |
| <b>Females</b>    |           |           |           |
| 11-14 years       | 35        | 600       | -         |
| 15-18 years       | 4         | 600       | -         |
| 19-65 years       | 40        | 600       | -         |
| 65+ years         | 40        | 700       | 10.0      |
| Pregnancy         | +10       | +100      | 10        |
| <b>Lactation:</b> |           |           |           |
| 0-4 months        | +30       | +350      | 10        |
| 4+ months         | +30       | +350      | 10        |

## Learning Outcomes

### MALNUTRITION

Strictly speaking malnutrition means 'poor nutrition'. It may include diets where nutrients are deficient (under nutrition) as well as those where nutrients are taken in excess (over nutrition). Both macro and micronutrients can be deficient or present in excess in a diet, and in all cases specific types of malnutrition are characterised by specific symptoms.

#### Protein energy malnutrition (PEM)

PEM is a term used to describe cases where the diet is severely deficient in both energy sources (fats and carbohydrates) and proteins, leading to specific deficiency symptoms. It is a common disease in many developing countries, particularly those where famines or civil wars have disrupted food production and distribution. In 1999 over a quarter of a million people, mainly children, died of PEM worldwide. PEM is much more common amongst children than adults, since children have smaller reserves in terms of fat stores, as well as higher energy and protein

requirements per kg body weight. PEM is rare in the developed world although may be seen in some groups including the homeless, drug addicts and some elderly people. If PEM persists for long periods of time, particularly in children, some or all of the following may result.

- ▼ Shorter stature (low weight for age)
- ▼ A wasted or emaciated body (low weight for height).
- ▼ The immune system may cease to function efficiently, making individuals more susceptible to infections.
- ▼ Tiredness and lethargy, brain growth and development may be retarded or permanently affected by severe PEM. Learning may be affected.
- ▼ Deficiencies of specific vitamins and minerals owing to low overall food intake, often with greatly reduced variety of foods.
- ▼ Severe and prolonged PEM can lead to organ failure and death.

Whilst some of the symptoms of PEM can be easily reversed once an adequate diet is available, PEM in childhood can have long term consequences. In many cases children who have been malnourished do not ‘catch up’ in growth terms and end up as smaller adults. This can affect their ability to perform hard manual tasks.

Whilst protein and energy deficiency have been discussed together here, previous classifications of malnutrition have recognised two distinct forms: **kwashiorkor** where protein deficiency occurred but energy was adequate, and **marasmus** where both were severely lacking. Kwashiorkor, was characterised by stunted growth (low height for age) and the presence of **oedema** (tissue fluid accumulating beneath the skin). This is thought to relate to the lack of proteins in the blood and leads to swollen cheeks, abdomen, feet, lower legs and hands. In contrast, marasmus, resembles an extreme form of PEM as described above where weight for age is only 60% of the expected value. It is now recognised that these two conditions are not clear cut and the term PEM is now used to cover both forms.

**Anorexia nervosa**

Anorexia nervosa literally means ‘loss of appetite through nervous causes’, although this description is not strictly accurate as the disease does not necessarily involve a loss of appetite. The disease is characterised by an obsessive desire to lose weight and become thinner. This is achieved through a combination of reduced food intake, and increased exercise. Sometimes vomiting and laxatives are used to rid the body of excess food which has been eaten. During this process the body image of the sufferer becomes distorted and they may perceive themselves to be fat even though their body weight is very low. At the same time, sufferers are often obsessed by food. Anorexia is thus a serious and specific disease with a psychological component, and not simply an extreme example of slimming for health or other reasons.

Anorexia nervosa primarily affects teenage girls from upper and middle class backgrounds in developed countries, although it does occur in boys, and has been noted in children as young as 6 years as well as in some adults. Some current estimates suggest that 1 in 100 adolescent girls will be affected by the disease. Whilst it is not a new disease, its frequency has increased dramatically in recent years. Anorexia may also co-exist with bulimia, another eating disorder.

The causes of anorexia are poorly understood, but it is regarded as a mental or psychological disorder, with a suggestion of some predisposing biological (genetic, hormonal) factors and social factors. Psychologists believe that the onset of the disease in adolescence may be linked to a subconscious desire to escape from the mental and physical changes to the body that occur at this time. Another theory is that it is linked to a conscious desire by individuals to take control of one aspect of their lives. Suggested triggers are stresses of relationships, low self esteem and failure in some areas of life. Once a teenager starts to become anorexic, hormone levels in the body fall and physical and mental growth and development may be halted. Initial success in achieving weight loss may reinforce attempts to continue.

Diagnostic criteria for anorexia nervosa include the following features:

- ▼ Body weight at least 15% lower than expected weight for age and height. This may be through weight loss or through failure to gain weight during growth periods
- ▼ An intense fear of gaining weight and a overwhelming desire to be thin
- ▼ Distorted perception of the body, and of the potential seriousness of the illness
- ▼ In girls, absence of at least three consecutive menstrual cycles (amenorrhoea.)

**Consequences of anorexia nervosa**

Common features of anorexia which have a detrimental effect on the body in both the short and long term are listed below.

- ▼ Reduced fertility in women. The low body weight of anorexia causes amenorrhoea and the menstrual cycle may continue to be affected even if weight is gained.
- ▼ Social isolation. This often occurs during the disease as sufferers shun social occasions where eating and drinking are involved.
- ▼ Organ damage. If anorexia continues for long periods then the kidneys, heart and other organs may fail through the stress placed on the body by low food intake, and may lead to death in about 3% of patients.
- ▼ Poor thermoregulation leading to low body temperature as subcutaneous fat is lost.

If vomiting and laxative use have been common features then the following may also occur:

- ▼ Dental problems caused by excessive vomiting and hence acid damage to tooth enamel.
- ▼ Bowel problems through the excessive use of laxatives.
- ▼ Mineral deficiencies through low intake and loss via vomiting and laxative abuse.

Anorexia nervosa is difficult to treat as its causes are not well understood and it is estimated that 60% of anorexia patients are left with long term consequences, both biological and psychological.

**Vitamin A deficiency**

As discussed previously the main functions of vitamin A relate to its roles in the formation of rhodopsin, in the maintenance of healthy skin and epithelial tissue, and in promoting growth. A prolonged deficiency of vitamin A will thus affect all three of these essential functions.

The three most common manifestations of vitamin A deficiency are set out below.

**Nightblindness.** Since Vitamin A is an essential to the functioning of rod cells in the retina, a deficiency will lead to poor adaptation to dim light where rod cells are most important.

**Xerophthalmia** or drying of the conjunctiva and cornea. Spots of keratinised epithelial cells (cells impregnated with keratin, the protein which makes dead skin hard) accumulate on the surface of the conjunctiva, and ulcers may occur on the cornea which are susceptible to infection by micro-organisms. Eventually these changes can cause blindness. It is estimated that 250 000 children per year become blind through vitamin A deficiency in developing countries.

**Thickening and drying of the skin**

**Vitamin D deficiency**

Since the main function of vitamin D is to control calcium metabolism in the body, deficiencies of the vitamin can have serious effects on bone growth and development. A lack of vitamin D in childhood (and indeed before birth when the vitamin is essential) can lead to the disease **rickets**. Rickets is a disease where low vitamin D levels mean that too little calcium and phosphate is added to growing bones. Bones may grow slowly and will also lack strength, and may be unable to support the body weight of the child. The legs bow under the strain and the spine and pelvis may also become bent and deformed. In severe cases this can make walking very difficult or impossible.

This condition is now relatively rare in the developed world, (partly due to the addition of vitamin D to many foods, including some dairy products and bread), although it was once common. As recently as the 1960s one study showed that 9% of children in Glasgow in Scotland showed symptoms. It is still relatively common across the developing world, even in regions where there are high levels of sunlight. There are thought to be two main reasons for this: firstly in some societies babies and children (especially girls in Muslim societies) may be tightly swaddled in clothes to shield them from the sun or kept indoors. Secondly, some staple foods, including Chapatti flour, contain substances which prevent the absorption of both calcium and dietary vitamin D. Asian children in the UK are at a higher risk of rickets than white children owing to lower levels of UV light absorption by darker skin, as well as dietary and socio-cultural factors.

In adults a deficiency of vitamin D leads to **osteomalacia**, a condition in which bones become weak and soft as they lose calcium. This can lead to bone and muscle pain and to fractures of bones, particularly the hip.

## Obesity

In medical terms a person is said to be overweight if their weight is more than 10% higher than the average for their height, and obese if their weight is over 20% higher than the average. Alternatively **body mass index (BMI)** which is:  $\text{weight in kg} / (\text{height in m}^2)$  can be used, with a BMI of 20-25 considered ideal. An obese man would have a BMI of 30 or more, a woman 28 or more.

Obesity is very common in Britain and other developed countries, far overshadowing the importance of any other nutritional disorders. Currently up to 30% of adults in England are defined as obese using these criteria, with an additional 40% of men and 26% of women being overweight. Perhaps surprisingly obesity is more common in the lower social classes in Britain. A growing proportion of children are also affected.

Causes of obesity may include physiological causes (such as an underactive thyroid gland) or be governed by a rare hereditary defect (e.g. Prader-Willi syndrome). Generally, however, it is the result of too much food and too little exercise. The foods taken in can be of any type: protein, fats, or carbohydrates as all can be converted to body fat. Many drinks, including soft drinks, beer and wine are also high in energy. Thus, in simple terms obesity arises when energy intake exceeds energy expenditure over an extended period. In fact, the latter factor (energy expenditure) is becoming increasingly significant: whilst the average calorie intake per person in the UK declined through the 1990s, the number of obese people increased.

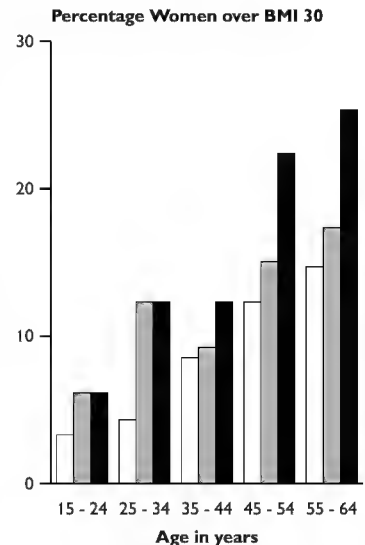
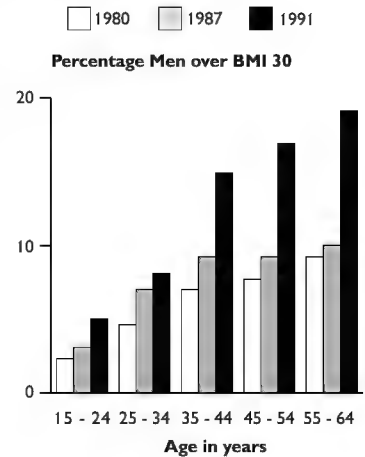
Environmental factors such as home environment are very significant in determining the likelihood of obesity. Children growing up with parents who are overweight are much more likely to become overweight themselves, even if they are adopted children who share no genetic similarities. Stress and depression may also lead to obesity in some people.

Consequences of obesity include:

- ▼ Damage to bones and joints. Excess body weight can put strain on the skeleton, leading to osteoarthritis, slipped discs and back problems. In general movement becomes more restricted and accidents may happen.
- ▼ Increased frequency of some cancers, including cancer of the gall bladder and intestine in men, and cancer of the ovaries and breast in women.
- ▼ Increased risk of cardiovascular disease, including high blood pressure (hypertension), atherosclerosis, thrombosis and myocardial infarction.
- ▼ Increased risk of type II diabetes, which seems to occur because obesity decreases sensitivity to the hormone insulin. This is itself linked to increased risk of cardiovascular disease.
- ▼ Psychological effects through loss of self esteem, teasing or bullying. May lead to depression and even suicide.

Most of the risk factors associated with obesity contribute to a shorter life expectancy in obese people compared to people of normal weight. For example a middle aged person who weighs 20% more than average has a 25% greater risk of death. Whilst this risk will be reduced again if weight is lost, the process of losing weight is lengthy and often proves very difficult.

Increasing levels of obesity



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## DIET and CORONARY HEART DISEASE

The cardiovascular system includes the heart and the blood vessels through which blood is pumped around the body. Cardiovascular disease is a term which covers several different diseases within this system, including **hypertension** (high blood pressure) **atherosclerosis** (narrowing of arteries with fatty deposits) and **coronary heart disease (CHD)**, a condition where fatty deposits (**atheroma**) that build up in coronary arteries can deprive the heart muscle of oxygen, leading to a heart attack. These three conditions are closely linked to each other and are all very common amongst adults in the developed world. Together they represent the main cause of death in British adults with around 110 000 people dying of CHD each year, and an additional 260 000 from strokes resulting from atherosclerosis.

**Atherosclerosis** is a condition in which the large arteries of the body become hardened and narrowed by the build up of deposits inside the artery wall. These deposits, which are known as atheroma (plural: atheromata) or **plaques** are composed primarily of cholesterol and other fatty materials, which are derived from the blood plasma. When atheroma builds up in the coronary arteries which supply the heart muscle, this condition and its associated effects, is known as CHD. Whilst atherosclerosis is usually only found in adults, atheroma deposits may start to build up from childhood.

Although the underlying mechanisms are not fully understood, atheroma build up is thought to begin in areas of the arteries which have been damaged in some way. Damage to the inner lining or **endothelium** may be caused by high blood pressure and overstretching of the artery walls or through chemicals derived from cigarette smoking, allowing lipids (especially cholesterol) in the plasma to enter the artery wall. The lipids accumulate beneath the smooth muscle layer, appearing initially as small fatty streaks which later become fibrous and hardened as connective tissue grows around the site. The artery wall will thus start to bulge into the cavity (lumen) of the vessel.

The effects of atherosclerosis include hypertension and thrombosis.

**Hypertension or high blood pressure** may be both a cause and a consequence of atherosclerosis. While the links between the two are not well understood atherosclerosis is thought to increase the risk of hypertension by increasing resistance to blood flow in two main ways. Firstly, atheromata increase friction between the blood and the lining (endothelium) of the artery, and secondly atheromata may reduce the elasticity of arteries (see section 5.2.3).

**Thromboses (singular thrombus)** are internal blood clots and are another major complication of atherosclerosis. Formation of a thrombus may be started if atheroma deposits in an artery wall rupture, exposing underlying connective tissue, to which blood platelets are attracted and stick. These platelets may then change their shape and nature, and secrete chemicals causing further platelets to stick to them, gradually forming a thrombus by means of mechanisms similar to that of blood clotting at a wound site.

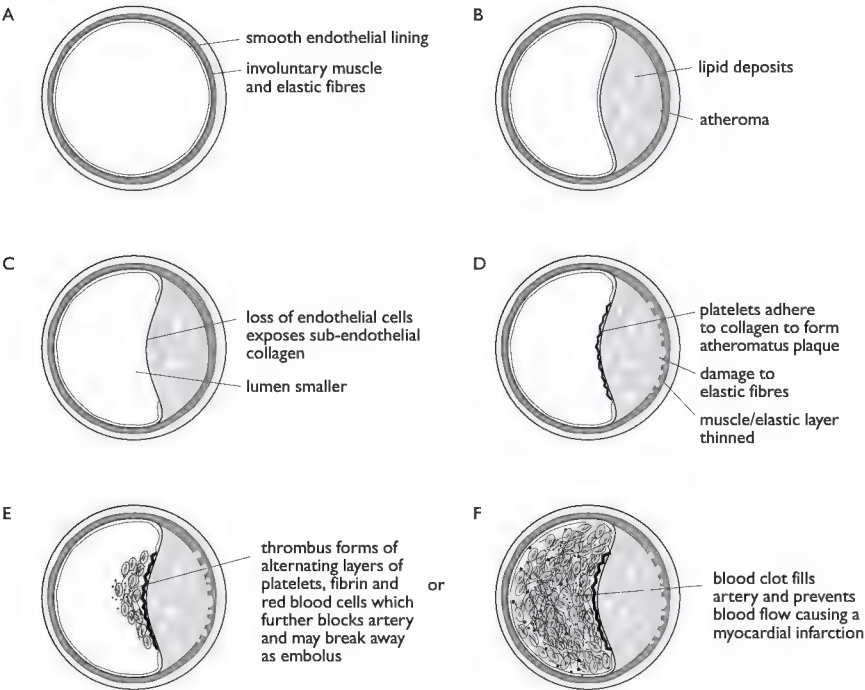
Once formed, the thrombus may cause damage in one of two ways. Firstly it may completely obstruct (block) the artery, preventing blood flow to areas of tissue. If the blockage occurs in a coronary artery

then this can lead to a heart attack or **myocardial infarction**, which occurs when parts of the heart muscle are starved of oxygen and glucose. Without oxygen and glucose the muscle tissue cannot respire and thus has no ATP for contraction of the muscle fibres. The heart then fails to contract properly which may be fatal.

Death of cardiac muscle in the heart wall (myocardial infarction), typically in the left ventricle, may occur suddenly without prior warning or may be preceded by pain in the chest region (**angina**). This pain is caused by narrowing of the coronary arteries and their inability to supply adequate oxygen to heart muscle and may be noted during exercise. Individuals suffering from angina will be carefully monitored and treated, to reduce the risk of myocardial infarction, through changes in diet and exercise and/or by drug treatment and occasionally by surgery (see section 5.2.4)

In other cases the thrombus may detach itself from the artery wall and enter the circulation. Known as an **embolus** this clot may then block a vessel in another part of the body. Clots may lodge in the pulmonary artery forming a pulmonary embolus, or in vessels of the brain leading to a stroke. Such blockages of vessels can lead to death, but if detected can be treated by giving drugs to break down the clot. People at risk of thrombosis may be given drugs such as warfarin (also used as a rat poison) or heparin which reduce blood clotting.

**Thrombosis**  
**Development in Coronary Artery**



**Risk factors in coronary heart disease.** There are a number of risk factors associated with CHD (it is said to be a multi-factorial disease). None of them are sufficient to bring about the disease on their own. Most act over a long period of time, and whilst some are avoidable, others, such as old age, are, of course, unavoidable. Some of the major factors are set out below:

- ▼ Genetic predisposition. One such example results in high cholesterol levels even when fat intake is low.
- ▼ Cigarette smoking. Chemicals in cigarette smoke are linked to artery damage and formation of atheroma.
- ▼ Hypertension or high blood pressure. Can damage walls of arteries and may play a role in initiating atheroma formation.
- ▼ Lack of exercise. Exercise helps to prevent obesity, and may reduce levels of LDLs in the blood (see section 5.2.3).
- ▼ Age. CHD is much more common in people over 40, although the accumulation of atheroma may begin in childhood.
- ▼ Gender. CHD is much more common in men than women in middle age.
- ▼ Obesity. Obese people are at higher risk due to increased blood pressure, increased strain on the heart.
- ▼ Dietary factors include high fat leading to high levels of cholesterol in blood plasma, also low fibre, high sugar, and high salt intake which is linked with raised blood pressure.

Whilst diet is only one of many risk factors in CHD, it is clearly a very important one and one which can be modified relatively easily to reduce risk.

A diet high in saturated fats (which are found mainly in foods of animal origin including dairy products and meat) can increase the risk of atheroma build up in arteries including coronary arteries by raising the level of blood cholesterol. There is a strong positive association between high levels of cholesterol and other saturated fats in the blood, and risk of CHD. Such lipids do not exist free in the blood but in compounds of lipid and protein known as Low Density Lipoproteins (LDL). LDLs are harmful as they are attracted to areas of vessel damage and can initiate the formation of atheroma.

In contrast, molecules known as HDLs-High Density Lipoproteins are formed when unsaturated fats combine with carrier proteins in the blood. High levels of HDLs seem to have a protective effect in CHD.

It should be noted that genetic factors as well as dietary factors play a role in determining the proportion of LDLs and HDLs in the blood. Some individuals eat a low cholesterol diet yet have unexpectedly high levels of LDLs in their blood, and need to monitor their diet with extra care.



Traditional Mediterranean diets are low in saturated fats, high in unsaturated fats (especially olive oil), high in fibre (from fresh fruits and vegetables), low in refined sugar and salt (due to a low intake of processed foods), with a moderate intake of red wine. In recent years it has been noted that people in Mediterranean regions (e.g. Greece and Italy) eating a traditional diet suffer much less from CHD than do people in Britain even though they have similar risk factors in terms of total food intake, smoking, and exercise levels. Such diets, or components of them, including 5 portions of fresh fruit and vegetables per day, are now recommended as one way of reducing the risk of CHD.

High fibre intake (from fruits, vegetables and whole grains) is thought to be beneficial in that it lowers levels of LDLs in the blood, perhaps through reducing absorption of lipids in the gut. Low sugar seems to be important in reducing the risk of diabetes which is itself a risk factor in hypertension and CHD, whilst high salt levels are thought to be important risk factors in hypertension. Red wine contains compounds known as 'antioxidants' which are thought to reduce the harmful effects of LDLs in the blood.

#### ◆ CHECKPOINT SUMMARY

- ◆ Protein and energy deficiencies frequently occur together as Protein Energy Malnutrition (PEM).
- ◆ PEM more common in children due to their smaller reserves and higher requirements. PEM in children has consequences for the rest of their lives.
- ◆ Anorexia nervosa is characterised by an obsessive desire to lose weight, and a distorted self-image, and is more common in adolescent girls in developed countries.
- ◆ Anorexia nervosa is a mental (psychological) disorder, involving predisposing biological and social factors.
- ◆ Vitamin A deficiency results in nightblindness, drying of the surface tissues of the eye (xerophthalmia) leading to blindness, and thickening and drying of the skin.
- ◆ Vitamin D deficiency results in poor bone growth and development in the young (rickets). In adults deficiency results in softening of the bones as they lose calcium (osteomalacia).
- ◆ Obesity is defined as being 20% heavier than the average for the particular group; or as having a Body Mass Index (BMI) greater than 30 in men, and 28 in women.
- ◆ Obesity is the major nutritional disorder in the developed world, and carries increased risk of other conditions, e.g. cardiovascular disease, type II diabetes, and cancer.
- ◆ Coronary heart disease is a multi-factorial disease (having many causes) and diet is a major factor.

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## 2.3.

### Gaseous exchange and exercise

#### Content

- The gaseous exchange system.
- The consequences of exercise.

#### Learning Objectives

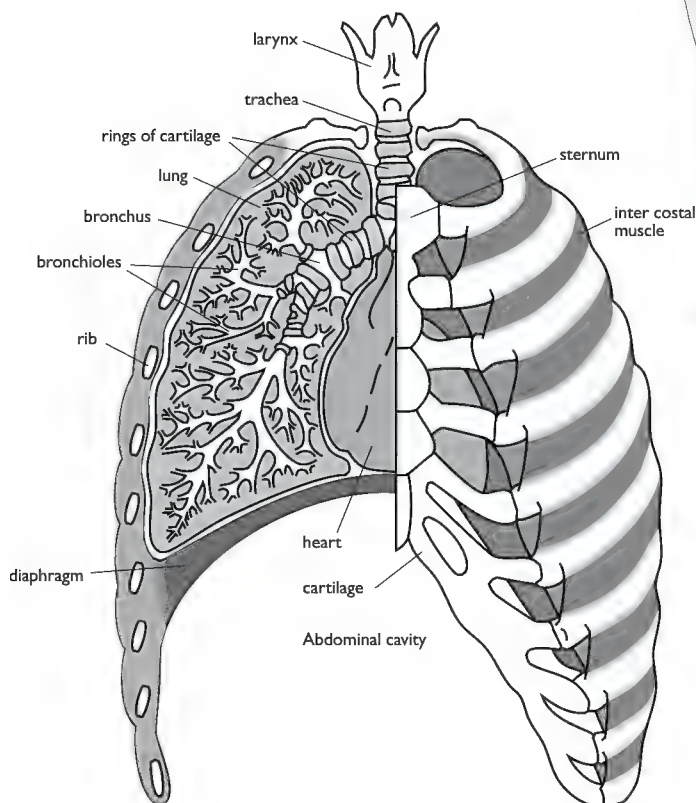
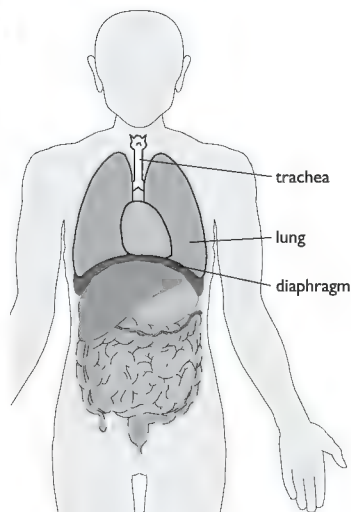
Candidates should be able to:

- a) describe the distribution of alveoli and blood vessels in lung tissue.
- b) describe the distribution of cartilage, ciliated epithelium, goblet cells and smooth muscle in the trachea, bronchi and bronchioles.
- c) describe the functions of cartilage, cilia, goblet cells, smooth muscle and elastic fibres in the gaseous exchange system.
- d) explain the meanings of the terms tidal volume and vital capacity.
- e) measure the pulse rate and understand that pulse rate is a measure of heart rate.
- f) explain the significance of resting pulse rate in relation to physical fitness.
- g) explain the terms systolic blood pressure, diastolic blood pressure and hypertension.
- h) explain the meaning of the term aerobic exercise.
- i) describe the immediate effects of exercise on the body, including the concept of oxygen debt and the production of lactate by anaerobic respiration.
- j) design and carry out experiments to investigate the effects of exercise on the body.
- k) appreciate how much exercise needs to be taken for significant sustained improvement in aerobic fitness.
- l) discuss the long term consequences of exercise on the body and the benefits of maintaining a physically fit body, relating these benefits to the concept that health is more than the absence of disease.

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## STRUCTURE and FUNCTION of the RESPIRATORY SYSTEM

One of the most fundamental of the life processes is gaseous exchange. Oxygen must be taken in from the air to the blood where it can be transported around the body to cells where it is used in respiration. At the same time, carbon dioxide, a waste product of respiration must be removed from the blood and released back into the air. This exchange of gases occurs within the alveoli of the lungs but relies on the specialised structure of the respiratory system (trachea, bronchi, bronchioles, alveoli), the breathing movements associated with the ribs and diaphragm, and the cardio-vascular system (heart, blood vessels and blood) to function.



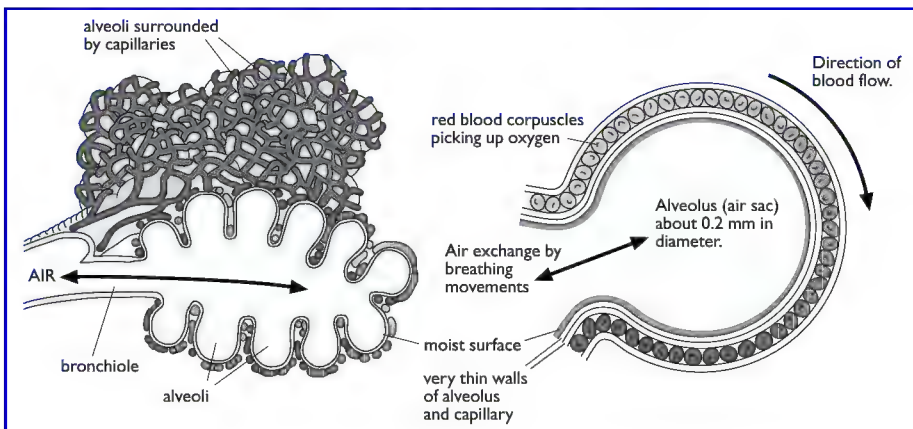
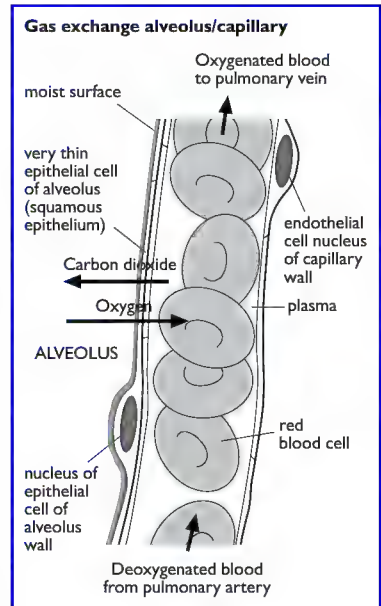
## Alveoli

Alveoli or air sacs make up the mass of the lungs. Within the chest cavity the major airway, the **trachea**, branches to form two **bronchi**, which in turn branch to form numerous smaller **bronchioles**. At the ends of the bronchioles the tubes, now only 1-2mm in diameter, become known as alveolar ducts which lead to the alveoli; small chambers used for gas exchange. Alveoli may be arranged along the alveolar duct in a linear fashion or may cluster together around a common opening to the duct. This arrangement is known as an alveolar sac. Although each alveolus is very small, the large numbers of alveoli provide an enormous surface area for gas exchange.

## Blood vessels

The blood vessels that supply the alveoli belong to the pulmonary circulation. Whilst other parts of the lung (including the bronchi and pleural membranes) receive blood from the bronchial arteries, it is the pulmonary arteries which supply blood for gaseous exchange. Deoxygenated blood enters the lungs via the pulmonary artery which initially splits into right and left branches and then follows the airways, branching through the tissue of the lungs.

Each alveolus is surrounded by a net of capillaries which together form the **alveolar-capillary complex**. As this name suggests, the endothelium of the capillaries is attached to the thin squamous epithelium of the alveolus via a shared basal membrane. The air inside the alveolus and the blood in the capillaries is thus separated by the thickness of two layers of cells. This is one feature that helps rapid diffusion of oxygen from alveolus to blood and carbon dioxide from blood to alveolus. Other features include the large surface area already mentioned, and the steep diffusion gradients which are maintained between the blood and the alveolus due to the constant movement of the blood and the constant ventilation of the lungs.



## STRUCTURE of the TRACHEA, BRONCHI and BRONCHIOLES

Trachea, bronchi and bronchioles form a system of branching air tubes referred to as the 'bronchial tree'. The wall of the trachea and bronchi are composed of four layers. These are the inner mucous membrane or **epithelial** layer, a **submucosa** layer consisting of connective tissue, elastic fibres and mucous glands, a layer of **smooth muscle** and **cartilage**, and a tough outer coat of **connective tissue**. When the the diameter of the bronchioles reaches 1 mm there is no cartilage, and they do not have mucous glands present in the submucosa. In very narrow bronchioles the smooth muscle and elastic fibres may form a single layer.

### Cartilage

Cartilage supports the trachea and bronchi and prevents their collapse. In the trachea the cartilage forms C-shaped rings which are arranged so that the open ends of the C are at the back of the tube, facing towards the spine. These support the tube and keep it open during inspiration expiration (breathing in and out). The incomplete nature of these 'rings' of cartilage allows a degree of compression due to the expansion of the oesophagus when swallowing food. In the bronchi the cartilage does not form rings but instead forms plates.

### Smooth muscle

Involuntary (smooth) muscle found in the trachea, bronchi and bronchioles can regulate the diameter of the tubes. In conditions like asthma and anaphylaxis, where constriction of the bronchioles occurs restricting air flow.

### Epithelium

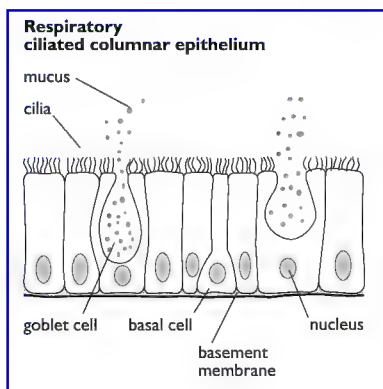
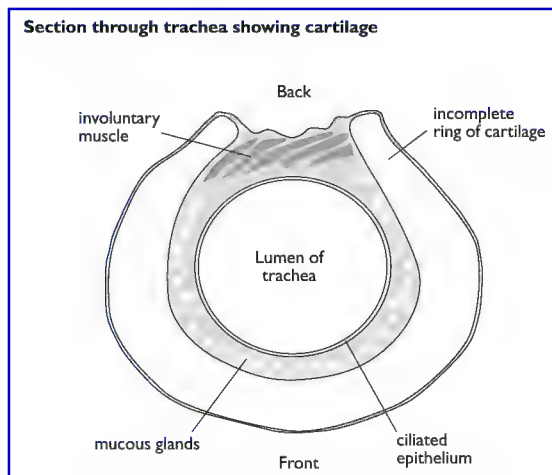
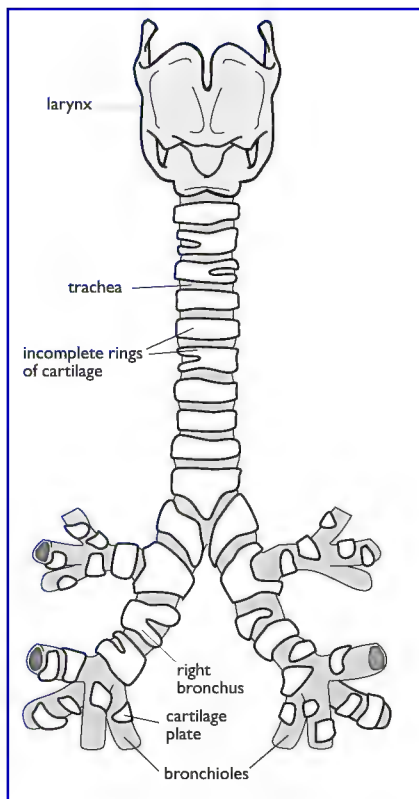
The epithelium lining the trachea, bronchi and bronchioles is known as the mucous membrane, and consists of ciliated columnar epithelium. This possesses three main cell types: ciliated cells, goblet cells and basal cells. At the very end of the bronchioles, close to the alveoli (the terminal and respiratory bronchioles) no goblet cells are found, only ciliated cells.

**Ciliated epithelial** cells have a protective function as they work in a co-ordinated fashion sweeping the mucus coat of the air passages which contains small inhaled particles such as dust towards the pharynx (throat and mouth) where they can be swallowed or removed by the cough reflex. This prevents such particles form entering the alveoli and interfering with gaseous exchange.

**Goblet cells** which are interspersed amongst the ciliated cells in the trachea and bronchi, are responsible for producing and secreting mucus within the respiratory tract. The layer of mucus which lines the airways traps dust and bacteria. It may also play a role in humidifying inhaled air.

### Elastic fibres

Elastic fibres confer elasticity upon the tissues, allowing contraction back to the original form after stretching.



#### ◆ CHECKPOINT SUMMARY

- ◆ The lungs have a huge internal surface area as a result of the millions of air sacs (alveoli).
- ◆ The pulmonary arteries supply the lungs from the right atrium, and the pulmonary veins return oxygenated blood to the left atrium of the heart.
- ◆ The pulmonary capillary beds supplying the alveoli are amongst the densest in the body.
- ◆ The lungs are organs composed of several specialised tissues.
- ◆ Cartilage supports the larger airways preventing collapse when the internal pressure of the thorax is reduced.
- ◆ Goblet cells secrete mucus which traps inhaled particles, and cilia sweep it up the trachea to be removed by the cough reflex.
- ◆ Smooth muscle fibres can alter the diameter of the airways by its contraction and relaxation.
- ◆ Elastic fibres enable the lung tissues to accommodate the changes in volume involved in breathing in and out, and enables breathing out to be passive by elastic recoil of the stretched tissues

## BREATHING and LUNG VOLUMES

For efficient gaseous exchange at the alveolar surface, air must be moved in and out of the lungs. This is achieved by the breathing movements of the intercostal muscles of the ribs, and the muscular diaphragm both of which are controlled by the autonomic and voluntary nervous systems.

During **inspiration** (breathing in) the external intercostal muscles contract pulling the ribs upwards and outwards. At the same time the diaphragm contracts, moving downwards. Both movements increase the volume of the thorax, reducing the pressure in the thorax below atmospheric pressure causing air to enter, inflating the lungs. At rest **expiration** (breathing out) does not involve active muscle contractions, but depends upon the elasticity of the tissues of the lungs and thorax.. The external intercostal muscles relax, allowing the rib cage to move downwards and inwards, and the diaphragm relaxes and regains its domed shape. The volume of the thorax is reduced, pressure increased and air forced out of the lungs. During forced breathing, for example as a result of exercise or in speech, expiration is active, with the internal intercostal muscles and abdominal muscles contracting to increase the pressure within the thorax.

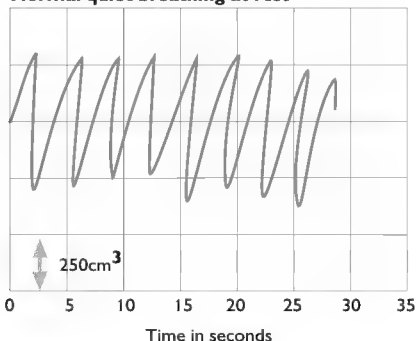
Friction between the lungs and the inner surface of the wall of the thorax is reduced by the **pleural fluid** which lies between the two pleural membranes that surround the lungs.

Breathing movements thus result in certain volumes of air passing into and out of the lungs.

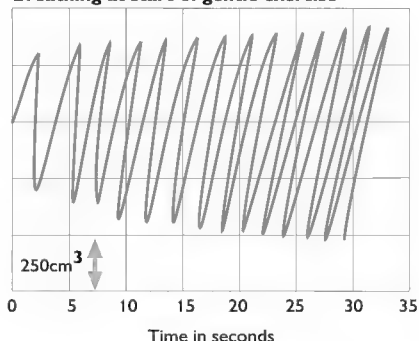
### Tidal volume

This is the volume of air breathed in and out in a single breath in a single breathing cycle. During normal quiet breathing at rest, a healthy, active mature male of average height would have a tidal volume of about  $500 \text{ cm}^3$ . Of this  $500 \text{ cm}^3$ , about  $350 \text{ cm}^3$  reaches the alveoli where gaseous exchange occurs. The remaining  $150 \text{ cm}^3$  fills the pharynx, larynx, trachea, bronchi, and bronchioles, which compared to the alveoli are poorly supplied with blood capillaries, so that very little, if any, gaseous exchange occurs here. This space where no gaseous exchange occurs is known as the anatomical **dead space**, and the air that occupies it as the **dead air volume**.

Normal quiet breathing at rest



Breathing at start of gentle exercise



The  $350\text{ cm}^3$  of the tidal volume that reaches the alveoli, mixes with the  $150\text{ cm}^3$  of air remaining in the dead space from the previous exhalation, so that  $500\text{ cm}^3$  of mixed air reaches the alveoli on each inspiration. Here it mixes with the air that remains in the alveoli in quiet breathing, the **stationary air volume**, which can be up to  $2500\text{ cm}^3$ . Thus the alveolar air consists of about  $350\text{ cm}^3$  of fresh air mixed with up to  $2500\text{ cm}^3$  of air that has undergone gaseous exchange with the blood, and  $150\text{ cm}^3$  of previous dead space air. Therefore the composition of alveolar air does not fluctuate widely during the breathing cycle, which in turn ensures that gaseous exchange with the blood also remains fairly constant throughout the breathing cycle. However, when the tidal volume increases during exercise, more 'fresh air' does reach the alveoli.

By breathing in as deeply as possible an extra volume of air, in addition to the tidal volume and the stationary air, can be taken into the lungs. This is the **inspiratory reserve volume** and can be up to  $2000\text{ cm}^3$ . By breathing out as forcibly as possible after returning to normal breathing, it is possible to expel some of the stationary air in addition to the tidal volume. This is known as the **expiratory reserve volume** and can be up to  $1500\text{ cm}^3$ . However the lungs cannot be emptied entirely, otherwise they would collapse, and this remaining air is known as the **residual volume** which can be up to  $1500\text{ cm}^3$ .

#### ◆ CHECKPOINT SUMMARY

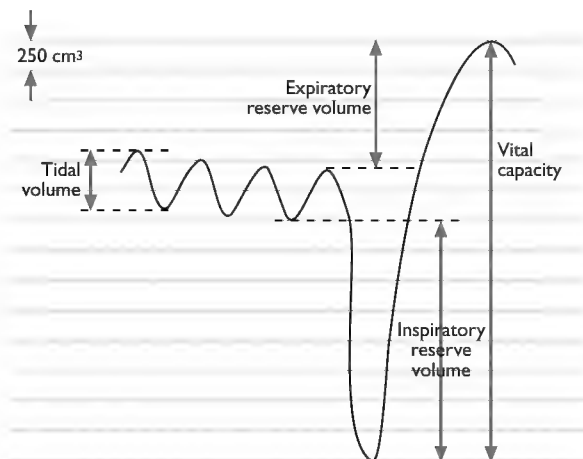
- ◆ Tidal volume is the volume of air breathed-in and out during a single breathing cycle.
- ◆ The tidal volume increases with aerobic exercise.
- ◆ The mixing of air in the alveoli results in a fairly constant level of oxygen in the alveoli, irrespective of the point of the breathing cycle.
- ◆ The vital capacity is the greatest volume of air that can be moved in and out of the lungs in one breathing cycle.
- ◆ The tidal volume cannot approach the vital capacity as it is not possible to move such volumes of air over the lungs during rapid breathing.
- ◆ Lung volumes are closely correlated with height.

### Vital capacity

This is the sum of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume. The vital capacity represents the maximum total amount of air that can be moved into and out of the lungs by one inhalation and one exhalation, and is about  $3000\text{ cm}^3$  -  $4000\text{ cm}^3$  in the adult male.

These volumes and the lung capacities vary considerably between individuals. They are generally smaller in females than in males, due to smaller average body size in females, and correlate closely with body size, height and surface area up to age 25. As discussed in section 5.2.4, smoking and associated lung diseases can considerably reduce lung volumes and capacities.

#### Vital capacity trace



This trace does not show the total lung volume and residual volume, which are not easily measured. With increasing age the residual volume increases from about 20% of the total lung volume to more than 30%.



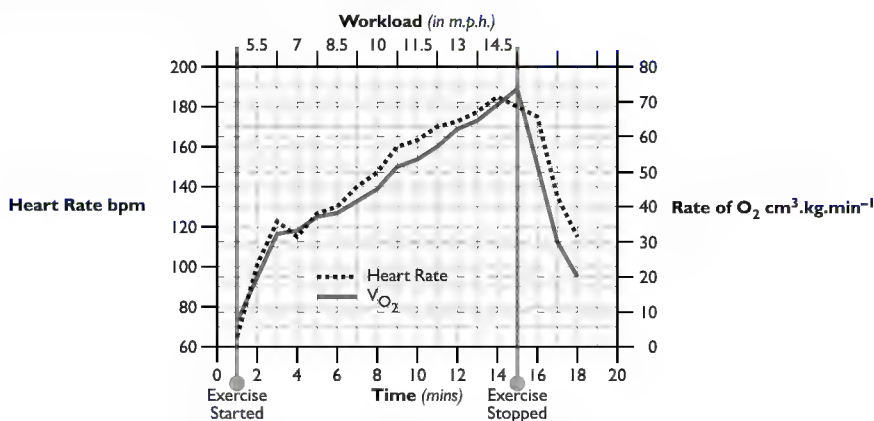
## HEART RATE and PULSE RATE

The mammalian heart works as a four chambered pump. The left atrium of the heart receives blood high in oxygen from the lungs and passes it to the left ventricle which pumps it around the body. Amongst other functions this supplies cells with oxygen and glucose for respiration. The right atrium of the heart receives blood low in oxygen from cells of the body and passes it to the right ventricle. It is then pumped to the lungs to collect oxygen and release carbon dioxide. A single heart beat represents the stages from filling of the atria to contraction of the ventricles which occur simultaneously on both sides.

As the ventricles of the heart contract, blood is forced into the main arteries leaving the heart, the aorta and the pulmonary artery. Blood enters the aorta at very high pressure and the thick elastic wall of the vessel is momentarily stretched as the blood enters. It then recoils as the blood moves on (causing stretching in the next section of artery). This recoil assists the circulation of the blood around the body, helps smooth the flow between contractions of the heart, and helps to maintain the blood pressure. This wave of stretching and recoiling in the walls of the arteries can be felt as the pulse in places where arteries come close to the surface of the body (the inside of the wrist, the side of the neck, and in the temple). The pulse thus reflects the rate of the heart beat and is the most common means of measuring heart rate. The pulse gradually fades as the arteries branch into the arterioles.

As the heart rate rises during exercise, owing to increased demand for oxygen and glucose by muscles, so does the pulse rate. A resting pulse rate (heart rate) of around 70 beats per minute can increase to over 200 during vigorous exercise. The maximum heart rate decreases with age, so that an estimate of your maximum heart rate can be given by the result of 220 minus your age.

Heart rate and oxygen uptake in response to exercise



The heart rate of individuals doing the same exercise may, however, vary considerably. Heart size varies between people, being usually though not always correlated with body size. In general the larger the heart the slower the maximum heart rate, as it takes longer for a larger heart to fill with blood between contractions. It is important to note that this is usually regarded as being beneficial since the rate at which blood is pumped into arteries and hence to tissues (the cardiac output), depends not only on the heart rate, but also on the amount of blood pumped out of the ventricles at each contraction (the **stroke volume**). The stroke volume is determined by the extent to which the ventricles fill with blood and by the force of contraction of the ventricles. These two factors are inter-related, the fuller the ventricles, the greater the force of contraction. Cardiac output is therefore equal to heart rate x stroke volume. Endurance training over long periods of time can lead to the enlargement of the heart - a condition known as athlete's heart.

**THE SIGNIFICANCE of RESTING PULSE RATE in RELATION to PHYSICAL FITNESS**

The **resting pulse** is defined as the pulse rate measured when an individual is at complete rest. It is usually taken when an individual is lying down first thing in the morning. It represents the response of the heart to basic metabolic demands of the body at rest (mental and physical). In general the larger and more powerful the heart of an individual (perhaps as a result of endurance athletic training) the lower will be the resting heart rate. This is because more blood will be pumped out of their ventricles on each contraction (the stroke volume is larger). Thus for a given cardiac output the heart rate is reduced, with some highly trained endurance athletes having resting pulse rates as low as 30 beats per minute.

It can therefore be said that as physical fitness (of the endurance type) increases, heart rate decreases, both at rest and during exercise of a given intensity. This is beneficial as it means that the heart is working less hard and has a lower oxygen demand. Another measure of fitness is the rate at which the heart rate returns to its resting rate after a set period of exercise at a given intensity, the faster the return to normal the greater the physical fitness.

## BLOOD PRESSURE

The heart pumps blood around a complete circuit of vessels, which offer resistance to the flow of blood, therefore pressures are generated within the system. Blood pressure is usually measured in the brachial artery in the left arm using a sphygmomanometer. It is measured clinically in mm of mercury (mm Hg). As a result of the action of the heart there are two measures of blood pressure.

### Systolic blood pressure

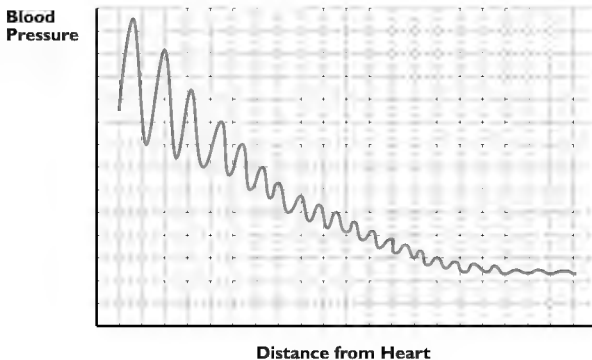
Systolic blood pressure is that pressure generated when the ventricles are contracting (about 120 mm Hg in a young healthy adult). A rough estimation of systolic blood pressure can be derived from adding 100 to your age.

### Diastolic blood pressure

Diastolic blood pressure is that pressure when the ventricles are relaxing (about 80 mm Hg in a young healthy adult). With regard to checking blood pressure, the diastolic pressure gives the clearest indication of the state of the resistance offered to flow by the blood vessels (peripheral resistance), as the heart is not contracting at this time.

Blood pressure is expressed as a ratio of systolic to diastolic blood pressure e.g. 120/80 mm Hg.

The average of the systolic and diastolic pressures during a complete cardiac cycle, known as the mean blood pressure, determines the overall rate of blood flow through the circulation. The blood pressure drops as the blood gets further away from the left ventricle and circulates around the body. Some typical figures for the mean blood pressure (in mm Hg) whilst at rest are: arteries 100, capillaries 18, veins 7, and at the entrance to the right atrium 3.



Blood pressure is generated by the cardiac output (heart rate x stroke volume) and the resistance to flow of the blood in the blood vessels. The resistance is often referred to as the peripheral resistance, as the major part of it occurs in the smaller vessels (mainly the arterioles) at a distance from the heart. The resistance

to flow is due to the friction between the blood and the walls of the blood vessels. The friction is determined by the length, diameter, and the smoothness of the lining of the vessels, and the viscosity of the blood. The shorter the vessel, the larger the diameter and the less viscous the blood, the lower the resistance. These features, particularly vessel diameter, are not fixed in an individual but change according to circumstances. Both acute (short term) and chronic (long term) changes can occur.

Arteries and arterioles (and to a lesser extent veins and venules) have involuntary muscle fibres in their walls, which when contracted constrict the vessel reducing its diameter. This can lead to short-term (acute) rises in blood pressure which occur at times of emotional stress, or following intake of certain drugs including nicotine. The systolic and diastolic blood pressures are also raised considerably during static (isometric), straining type exercises, as in weight training. This is caused by compression of the peripheral blood vessels, causing an increase in the resistance to blood flow and a demand for increased blood pressure, to maintain the circulation to the contracted muscles. Acute increases in blood viscosity, which lead to increased resistance and increased blood pressure can occur during periods of dehydration due to excess water loss in sweating, or in the urine following consumption of substances that increase urine production (diuretics) such as alcohol and caffeine.

## Hypertension

Hypertension is chronic high blood pressure as a result of permanently high peripheral resistance. There is no universally agreed clinical definition of hypertension nor any reliable signs and symptoms, but a systolic blood pressure over 160mm Hg and diastolic blood pressure over 95mm Hg on several consecutive readings would lead to a definite diagnosis of this condition. Pressures of 140/90 mm Hg may be borderline (compared to average values of 120/80 mm Hg in a healthy young person.) There is, however, much natural variation in blood pressure between individuals, making diagnosis more difficult

Whilst hypertension is one of the most common disorders in the developed world, particularly amongst older people, in most cases there is not a single causative factor. It is thought to be linked to activity of the sympathetic nervous system causing excessive vasoconstriction and to disturbance in the salt and water balance of the body. Suggested causes are high salt diets and obesity. Smoking-related lung disorders (see section 5.2.4) can lead to pulmonary hypertension. The consequences of hypertension include having increased risk of developing atherosclerosis, cerebral haemorrhage and kidney failure.

Regular aerobic exercise over a period of time can result in a lowering of the resting systolic and diastolic blood pressures. Exercise of this type decreases the peripheral resistance as the circulation becomes more efficient, increases the ratio of the high density to low density lipoproteins in the blood, and together with the appropriate diet aids weight loss.

### ◆ CHECKPOINT SUMMARY

- ◆ The surge of blood pumped out of the heart into the arterial system and the subsequent recoil of the arterial walls when the heart relaxes is felt as the pulse.
- ◆ The pulse rate is thus determined by the heart rate.
- ◆ The resting pulse rate is a measure of physical fitness. At rest, the metabolic demands of similar individuals are approximately the same, and are met by the cardiac output.
- ◆ The cardiac output is the product of the heart rate and the stroke volume.
- ◆ The individual with the lower resting pulse rate is meeting those demands with the same cardiac output, and must therefore have a higher stroke volume. Stroke volume is proportional to the size and power of contraction of the heart. A large powerful heart is a major component of aerobic physical fitness.
- ◆ When the ventricles contract (ventricular systole) the systolic blood pressure is generated as a result of the resistance to flow within the arterioles.
- ◆ When the ventricles relax (ventricular diastole) the pressure in the arterial system drops and is known as the diastolic blood pressure.
- ◆ These pressure changes are felt in the pulse.
- ◆ A complex of factors including a loss of elasticity in the walls of the arterial system with age, narrowing of arteries by fatty deposits, and increased blood volume, lead to increased resistance to flow and hence higher blood pressure or hypertension.
- ◆ Short term (acute) rises in blood pressure can occur in response to specific situations as a result of anxiety, such as 'white coat hypertension' when people enter a medical environment.
- ◆ Long term (chronic) rises in blood pressure (essential hypertension), especially diastolic blood pressure, indicate a permanent rise in resistance to flow in the arterial system.
- ◆ Hypertension carries risks, particularly to the kidneys, and the brain where ruptured blood vessels result in 'strokes'.

## Aerobic Exercise

Exercise can be basically divided into two types. **Aerobic exercise**, for example jogging, where oxygen supply to the muscles meets the oxygen demand of the muscles for the release of energy by aerobic respiration; and **anaerobic exercise** where oxygen supply to the muscles does not meet the oxygen demand of the muscles for aerobic respiration (anaerobic means 'without oxygen'). Both systems may operate together, but typically one predominates in a particular type of exercise. Many sports and games which require sudden bursts of effort such as football, combine periods of both aerobic and anaerobic exercise.

Aerobic exercise enables sufficient oxygen to be delivered to working muscles by the blood, and as a result carbohydrates and fats inside cells can undergo complete oxidation, being converted into carbon dioxide and water, with the release of energy in the form of ATP. It occurs in cells whilst the body is at rest and during endurance type sports. The following equation can be given for aerobic respiration:



Aerobic respiration take place in three main stages. The first, **glycolysis**, occurs in the cytoplasm of cells, does not involve oxygen directly and releases a small amount of ATP very rapidly. The second, which releases most of the energy, occurs in the matrix of the mitochondria, and the third in which the energy is trapped as ATP on the inner membranes (cristae) of the mitochondria. In this way molecules of ATP are released from the complete oxidation of one molecule of glucose.

Aerobic exercise, unlike anaerobic exercise, can be maintained over long periods of time (many hours or even days) as long as there are sufficient fuel supplies. The increased production of carbon dioxide which occurs has a direct effect on the cardiac and respiratory control centres in the brain. In lowering blood pH it stimulates an increase in the cardiac output (increase in heart rate and stroke volume) and an increase in the rate and depth of breathing which adapt to the level of exercise being undertaken. Marathon running and swimming the Channel are good examples of aerobic exercise lasting several hours.

## Anaerobic Exercise

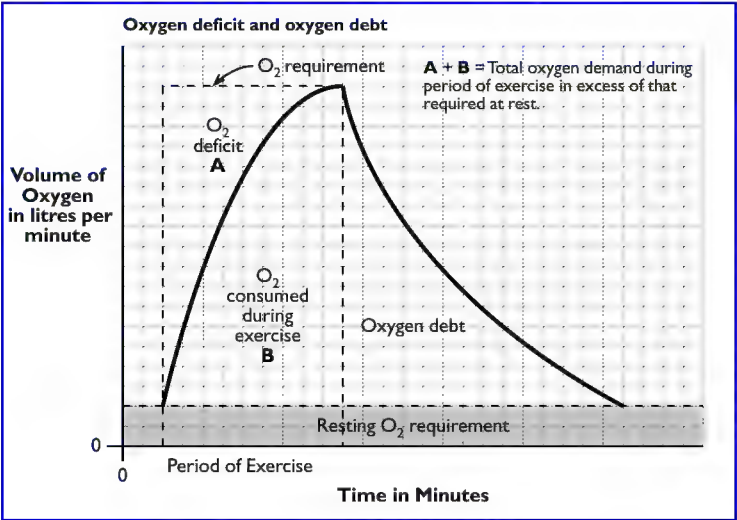
Whenever the demand for oxygen during exercise is greater than its supply, the muscle fibres are forced to release energy from their energy stores anaerobically, without oxygen. This can occur at the onset of vigorous activity, or at any time during exercise when the effort is increased above a certain level, and when the heart and circulation have not had time to adapt to the increase in demand. In the absence of oxygen the breakdown of glucose is incomplete, with the production of lactic acid and the rapid release of relatively small amounts of energy (2 molecules of ATP per molecule of glucose: only 5% of what can be released aerobically). The equation for anaerobic respiration, which occurs in the cytoplasm of muscle fibres is:



Note that under the conditions existing inside the body the lactic acid dissociates to form hydrogen ions and lactate ions, so it is preferable to refer to **lactate** rather than lactic acid (which remains in common usage).

A small amount of lactate is formed even during the lightest exercise as not all muscle fibres will be sufficiently supplied with oxygen, especially at the start of exercise. However, if its rate of removal is more than or equal to its rate of production, it does not accumulate in the muscles or the blood. It is transported in the blood to organs which are not operating under anaerobic conditions, such as the heart, brain and liver, where it can be oxidised. When the rate of production does exceed its rate of removal, lactate begins to accumulate in the muscles and the blood. The resulting reduced blood pH (increased acidity) increases fatigue, and increases the rate of breathing, eventually past even the point at which any extra oxygen uptake can be achieved. It is around the start of this process of lactate accumulation during exercise that conversations tend to stop! Past a certain upper limit the anaerobic respiration will cause enough distress to force the activity to stop.

**Oxygen debt** is a concept relating to the fact that whilst exercising anaerobically the body can be considered to be short of a certain amount of oxygen (the **oxygen deficit**) and that after exercise, breathing and cardiac output remain high for a period of time to supply an amount of oxygen equivalent to that amount undersupplied during exercise. Originally the extra amount of oxygen required during recovery, was assumed to be just that which was needed for the removal of the accumulated lactate (by aerobic respiration to carbon dioxide and water, yielding ATP) and was therefore referred to as the 'oxygen debt'. However, there is only a slight relationship between the oxygen deficit and the so-called 'oxygen debt'; with the 'oxygen debt' being up to twice the oxygen deficit. Therefore the 'oxygen debt' is not simply involved with the repayment of a deficit incurred during exercise. It also compensates for the extra oxygen needed after the period of anaerobic exercise,



including that needed to supply the muscles of the thorax responsible for the increased breathing rate, and the more rapid beating of the heart. Also the oxygen required to maintain the higher metabolic rate due to the raised body temperature, and the residual effects of the hormones adrenaline and thyroxine. The redistribution of ions (such as calcium, potassium and sodium) in the fluids inside and outside of cells after exercise, also requires energy and therefore oxygen. In recovery from strenuous exercise, which has resulted in the production of lactate, it may be as long as 24 hours after stopping exercise before the oxygen consumption returns to pre-exercise levels.

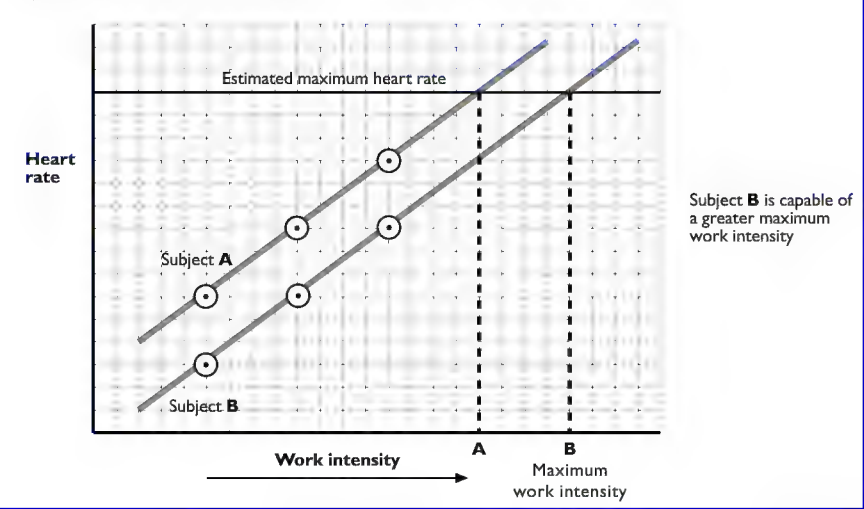
### EXPERIMENTAL INVESTIGATION of the EFFECTS of EXERCISE on the BODY

Experimental investigations into the effects of exercise can be performed during sub-maximal or maximal exercise. In **sub-maximal exercise**, measurements are taken in a zone of exercise intensity that the subject finds comfortable, and from these it is possible to project trends to determine maximum values of, for example, work intensity or oxygen uptake. Such projections depend on various assumptions. One assumption is that there is a straight line relationship between the two measurements being taken, e.g. heart rate and exercise intensity, and heart rate and oxygen uptake. In other words as the independent variable increases (e.g. exercise intensity) the dependent variable (e.g. heart rate) increases proportionally). Another assumption is that the maximum heart rate can be estimated accurately by means of the formula: maximum heart rate = 220 minus the age of the subject. For example in the case of a 20 year old this would give a maximum heart rate of 200 beats per minute. Thus if a subject is exercising at three sub-maximal work intensities, and three heart rates are measured at

#### ◆ CHECKPOINT SUMMARY

- ◆ Aerobic exercise is at that intensity at which the demand for oxygen by the active muscles can be met by the supply of oxygen in the blood.
- ◆ Aerobic exercise is characterised by relatively low intensity for relatively long periods, during which the body is in a 'steady state', and conversation is possible.
- ◆ Anaerobic respiration occurs when the demand for oxygen by the tissues is not met by the supply of oxygen in the blood.
- ◆ Anaerobic respiration results in the rapid release of relatively small amounts of oxygen and the production of lactate as a by-product.
- ◆ When the intensity of exercise eases, and/or the circulatory and respiratory systems have adjusted to supply the demand for oxygen by the working muscles, the accumulated lactate is oxidised.
- ◆ The oxidation of the accumulated lactate uses a volume of oxygen equivalent to the amount that the body was short of during the anaerobic exercise.
- ◆ In this way the 'oxygen debt' is paid off.
- ◆ The excess post-exercise oxygen consumption (EPOC) is greater than the 'oxygen debt' as there are many post-exercise processes which demand extra oxygen until the metabolism returns to its resting levels.

Projections from sub-maximal work



these intensities, then a line can be drawn and extended to the calculated maximum heart rate, and an estimate of the maximum work intensity be obtained. Estimating the maximum heart rate by using the formula ‘maximum heart rate = 220 minus the age of the subject’ is not very accurate, as everybody varies slightly and endurance trained athletes can develop a larger heart and thus a lower maximum heart rate. In these cases the maximum work intensity would be overestimated by using the formula.

Despite these inaccuracies sub-maximal tests have the advantage over maximal tests in that they avoid the question of motivation (whether the subject really was exercising maximally). Also the subject is not unduly stressed, which could be dangerous if the subject has any condition made worse by intense effort, such as certain heart conditions.

Methods of controlling and measuring work intensity are required for all tests of the effects of exercise on the body, and these include the simple step test, treadmill, and cycle ergometer.

Fitness is very specific, and usually runners perform better on the treadmill, and cyclists on the cycle ergometer. The step test is more ‘event neutral’, but even here differences in height and coordination will affect the outcome.

EXERCISE and AEROBIC FITNESS

Defining and measuring fitness is difficult, but fitness can be thought of as the capacity to perform repeated physical activity with relative success and enjoyment. With some strenuous sports, the exertion is so great that it could hardly be considered enjoyable at the time, however in these cases the enjoyment derives from the sense of achievement that follows the exertion. Any discomfort experienced is generally soon forgotten as a result of the body's rapid recovery. Indeed a common measure of fitness is the speed of recovery after exertion. In less physically demanding skill-based sports, physical fitness can be considered as that state which prevents fatigue from interfering with the performance of the skill.

Perhaps the clearest definition of physical fitness would be to relate it to the ability of the body to respond to the physical demands made upon it by improving its capacities, that is a person responds to physical demand by becoming ‘fitter’. This is the main principle of training practices, namely progressive overload with adequate recovery leading to adaptation. A battery of tests exists for investigating various anatomical and physiological systems, and the results of these tests can in turn be used to define various levels and categories of ‘fitness’.

**Significant sustained improvement** in aerobic fitness can be achieved by raising the pulse rate in steady state aerobic exercise up to the point of conversation becoming difficult (if running in company) for about three 30 minute sessions a week. Gains made in aerobic fitness only persist if the exercise is maintained. Should the exercise be stopped for some reason, gains in fitness are lost. The rate of loss is approximately three times more quickly than the rate of gain.



## LONG TERM CONSEQUENCES of EXERCISE: FITNESS and HEALTH

Exercise has long been recognised as an important component of the physical health of individuals, and has been incorporated into formal education programmes in schools for well over a century. More recently it has been recognised that exercise can help to reduce the risk of illness or death from some of the degenerative diseases which are becoming increasingly common across the world. Exercise is thus promoted as a preventative measure in a range of diseases. It has also been suggested that exercise may benefit the mental well-being of individuals, leading to overall improvements in health (see section 5.2.1 for definition of health).

Components or dimensions of physical fitness relating both to sport performance and general health include:

**Cardio-Respiratory endurance** - the capacity/ability to sustain aerobic work.

**Muscular endurance** - the ability to sustain local muscle action.

**Strength** - that force exerted by muscles in a single maximal contraction.

**Mobility/Flexibility** - the range of movement about the joints.

**Body composition** - the relative amount of body fat compared to lean body mass.

**Speed** - the quickness of action of either whole body or part body movements.

**Power** - the work performed in a given time, a combination of strength and speed.

**Agility** - the ability to alter the position of the body and/or its parts, quickly, and accurately in a controlled manner.

**Balance** - the ability to control the position of the centre of gravity/mass and maintain it within and above the area of the base of support.

**Co-ordination** - the ability to combine the action of various parts of the body in a controlled manner.

Health benefits of exercise are not easily demonstrable, but there is an accumulation of reliable scientific evidence that sustained (regular) aerobic exercise of the correct type promotes what is generally understood as good health, both physical and mental, in young and old alike. It may play a significant role in preventing early death but does not necessarily increase longevity above average. Individuals should thus aim to make regular exercise a part of their lifestyle, even if this exercise is only walking and climbing the stairs instead of using cars and escalators. There is no universally agreed level of exercise above which health benefits may be felt, but with the increasingly sedentary lifestyles of western populations any increase in exercise is likely to be beneficial.

The most widely appreciated of these benefits relate to the effects of exercise on the cardiovascular system. These effects, many of which overlap, can be summarised as follows:

- ▼ Reduction in or prevention of obesity through increased utilisation of body fat.
- ▼ Reduction in risk of hypertension through a decrease in the peripheral resistance

- ▼ Reduction in ratio of harmful LDLs (cholesterol) to protective HDLs in the blood
- ▼ Reduction in the risk of Type II diabetes (late onset type) through maintaining the sensitivity of the tissues to insulin
- ▼ Reduction in risk of coronary thrombosis through increased blood flow through the coronary arteries and increased fibrinolytic activity (breakdown of clots) within the blood.
- ▼ Lowering of average heart rate during sub-maximal exercise and at rest, so reducing the demands on the heart.
- ▼ Improvement in the stability of the electrical activity of the heart, which decreases the risk of life threatening disturbances in their pattern (as seen in the ECG trace).
- ▼ Reduction in stress through aiding relaxation and improving the quality of sleep.

In summary, vigorous aerobic exercise at least three times a week reduces the risk of a myocardial infarction (heart attack) by at least 50%.

In addition to these benefits on cardio-vascular health, exercise of all types has a beneficial effect on the musculo-skeletal system. Muscles, tendons, ligaments and bones all weaken as a result of disuse. During prolonged inactivity up to a third of the calcium salts, which are responsible for the hardness of bone, can be lost in a process of demineralisation, leading to the weakening of the bone known as osteoporosis and increased risk of fractures. Exercise protects against this bone loss, and can more than compensate for the loss of bone mass that occurs in post-menopausal women. Exercise can also increase the tensile strength of tendons and ligaments, and as a result of the release of growth hormone stimulates the synthesis of tissue protein especially in the muscles.

Other effects of exercise which are often quoted although difficult to prove scientifically, include improved appearance, improved confidence about one's body, improved quality of skin and hair, improvements in mood and improved sociability. If such effects are real phenomena, mediated by physical or mental changes in the body, then it is likely that they will contribute significantly to overall health, including the social and mental dimensions of health. Such benefits are however, only maintained if the exercise is sustained.

All these benefits of maintaining a physically fit body illustrate the concept that health is more than the absence of disease.

Whilst many aspects of exercise are positive, and regular carefully graded aerobic exercise in itself carries very little risk, there can be negative effects. Over-exertion and over-training in some individuals can lead to extreme tiredness and excess weight loss perhaps in association with some eating disorders. In addition the activity of the immune system may be depressed for a period of up to 24 hours after exhaustive exercise, opening the way for infection. Care should also be taken to avoid over-exertion whilst infected, as this may be a factor in the development of long term (chronic) conditions such as 'glandular fever', post-viral fatigue syndrome, M.E. (Myalgic Encephalomyelitis), or even some forms of heart disease (myocarditis). There is also the possibility of overuse injuries to the musculo-skeletal system such as pulled muscles, back problems, and stress fractures of bones. In extreme cases over-vigorous anaerobic exercise in untrained individuals at risk of CHD can lead to death from myocardial infarction.

#### ◆ CHECKPOINT SUMMARY

- ◆ Exercise experiments can be maximal or sub-maximal.
- ◆ Sub-maximal exercise experiments are safer and easier to control than maximal exercise experiments.
- ◆ Standardised exercise protocols are necessary, e.g. step test, cycle ergometer, and treadmill.
- ◆ Aerobic fitness can be improved by a simple regime of 30 minutes of steady exercise three times a week.
- ◆ Gains in aerobic fitness are lost three times more quickly than they were achieved.
- ◆ Exercise has long term benefits for health, including reduced risk of cardiovascular disease, type II diabetes, hypertension, obesity etc.
- ◆ The improved statistics associated with aerobic exercise persist only for as long as the exercise is maintained.

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## 2.4

### Smoking and disease

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#### Content

- ▼ Effects of smoking and disease on the gaseous exchange and cardiovascular systems.
- ▼ Prevention and cure.

#### Learning Outcomes

Candidates should be able to:

- a) describe the effects of tar and carcinogens in tobacco smoke on the gaseous exchange system
- b) describe the symptoms of chronic bronchitis and emphysema (chronic obstructive pulmonary disease) and lung cancer.
- c) evaluate the epidemiological and experimental evidence linking cigarette smoking to disease and early death.
- d) describe the effects of nicotine and carbon monoxide in tobacco smoke on the cardio-vascular system with reference to atherosclerosis, coronary heart disease (CHD) and strokes.
- e) discuss the reasons for the global distribution of CHD.
- f) discuss the difficulty in achieving a balance between prevention and cure, with reference to CHD, coronary by-pass surgery and heart transplant surgery.

#### SMOKING and DISEASE

As discussed previously, the main causes of ill health and premature death in the developed world, and indeed in some cities within the developing world, are the non-infectious diseases. Often known as diseases of urbanisation, diseases of affluence or degenerative diseases, these include cancers, cardio-vascular diseases, obesity, diabetes and a range of mental disorders and addictions. As well as being associated with older age, many of these diseases have links with high fat, high calorie and low fibre diets, lack of exercise, mental stress, high alcohol intake and excessive smoking.

Many of these factors interact with each other making the effects of each difficult to distinguish, but smoking tobacco is known to be the largest single cause of preventable death and ill health in Britain. The strong links between smoking and lung cancer, chronic bronchitis, emphysema, and cardio-vascular disease are well established. Similarly, it is associated with increased risk of a range of other types of cancer and other respiratory diseases.

Today around 6-700 billion cigarettes are produced world-wide each year and in excess of 4 million deaths result from their use. World Health Organisation (WHO) predictions suggest that this will rise to 10 million in 2010. Whilst some developed countries now show a slight decline in smoking, (perhaps as a result of increasing cost, changing social customs, public health warnings and increasing health education) the number of smokers in developing countries continues to increase.

## EFFECTS of TOBACCO SMOKING on the RESPIRATORY SYSTEM

Tobacco smoke contains a mixture of many substances including irritant carbon particles, droplets of **tar**, the addictive chemical **nicotine** and a mixture of hot gases including the poisonous **carbon monoxide**. Of more than 1000 components identified more than 17 are known to be carcinogenic (cancer-causing). Many others are harmful in different ways, as demonstrated in studies on animals and observations in humans.

The effects of tar and other carcinogens in tobacco smoke on the gaseous exchange system are numerous. As discussed previously, efficient gaseous exchange relies on respiratory surfaces in the lungs having a large surface area, a short distance over which diffusion must occur, an effective ventilation mechanism and a good blood supply to deliver oxygen and remove carbon dioxide. It also relies on a network of airways to deliver air to these respiratory surfaces and mechanisms to limit the chance of dust or micro-organisms entering the lungs. Smoking can decrease the efficiency of all of these features in the following ways:

- ▼ Carbon monoxide binds to haemoglobin in red blood cells reducing the oxygen carrying capacity of the blood.
- ▼ Collection of tar on the alveolar surface increases the diffusion distance for gaseous exchange.
- ▼ Tar and other substances inactivate cilia and prevent them from clearing respiratory passages of dust and micro-organisms which can reach the alveoli leading to irritation and increased risk of infection.
- ▼ Inflammation of the bronchioles by tar and smoke causes constriction and secretion of fluid and mucus allowing less air into and out of the lungs (Bronchitis). Smoking may also make asthma worse.
- ▼ Nicotine may also cause constriction of bronchioles as a result of stimulating contraction of the smooth muscle in the walls of the 'bronchial tree'.
- ▼ Carcinogens in tar may lead to lung cancer which can eventually destroy large parts of the lung, preventing gas exchange.

All the effects mentioned above are positively correlated with the number of cigarettes smoked, but there appears to be a significant genetic variation between individuals in the extent to which smoking affects lung function. Thus one individual may smoke only 5 cigarettes per day but develop severe emphysema by the age of 40 and lung cancer by 45, whilst another person may smoke 40 cigarettes per day and show no signs of associated ill health by the age of 90.

Even those exposed to the smoke of other people's cigarettes (**passive smoking**) are at an increased risk from a range of smoking related diseases. In families in which there is at least one heavy smoker, non-smoking individuals suffer 50% more respiratory illnesses than those coming from a non-smoking family. In addition, a large number of people have allergic reactions to tobacco smoke, which could be dangerous to those at risk from asthma, chronic bronchitis and CHD. A further subset at risk from passive smoking, are unborn babies who receive harmful substances from smoking across the placenta. Low birth weight, prematurity and increased risk of infant mortality are all associated with mothers smoking during pregnancy whilst perhaps as many as 1500 fetal deaths occur each year in the UK as a result of smoking.

## CHRONIC BRONCHITIS and EMPHYSEMA

These two conditions are closely linked and often considered together even though they each have distinct symptoms and signs. Together they are referred to as chronic obstructive airways disease (COAD) or **chronic obstructive pulmonary disease** (COPD). Between them they affect 17% of British men and 8% of women in the 40-64 age group, and, worldwide, cause well over 2 million deaths per year. Both conditions are almost entirely due to cigarette smoking. Sufferers may become so disabled that they are breathless even at rest and require oxygen cylinders at home.

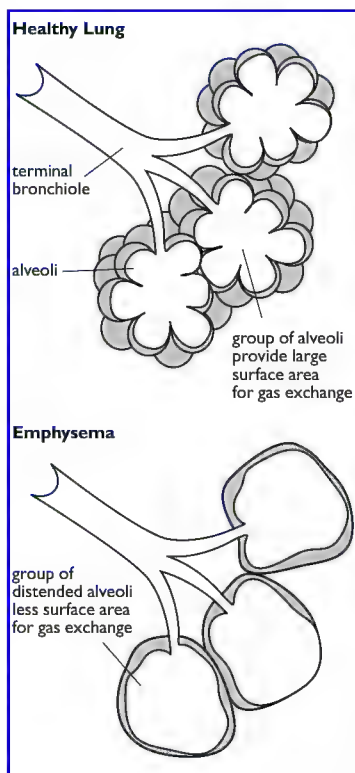
### Chronic Bronchitis

This is a clinical term and is defined as a chronic cough producing sputum (mucus from the lungs) for at least three months each year in two consecutive years. It involves inflammation of the bronchi and bronchioles which is caused by the irritant effect of tar and other substances in cigarette smoke. This inflammation causes thickening of the mucosal linings of these airways and over-secretion of mucus by glands in the larger airways and by goblet cells in the epithelium. These changes are responsible for the obstruction of the airways and in turn result in symptoms of wheeziness and breathlessness. In addition the excess mucus irritates the lungs causing the person to cough in an attempt to remove it. Further effects of bronchitis include increased frequency of lung infections, as bacteria thrive in the mucus. These infections, including pneumonia can make all the symptoms of bronchitis worse.

### Emphysema

This is a condition defined by the enlargement of air spaces in the lungs as a result of the destruction of the walls of the alveoli. As these run together there is a reduction in the surface area over which gas exchange can occur. At the same time the airways become obstructed, and the lungs lose their elasticity. Instead of staying open during exhalation the smaller airways collapse preventing much of the air from being breathed out. Exhalation may require conscious effort. The result is breathlessness, fast, shallow breathing (hyperventilation), wheezing and difficulty in performing even basic activities such as walking short distances. The onset of emphysema is usually slow and gradual, and sufferers often live with this disabling disease for many years before death.

Like chronic bronchitis, emphysema is closely linked to smoking and the cause is thought to be related to the action of elastase and protease enzymes in the lungs. Such enzymes, released by granulocytes (white blood cells) break down the walls of the alveoli. Under normal conditions these enzymes work alongside anti-protease and anti-elastase enzymes, keeping a balance between breakdown and regeneration of alveoli. In smokers, however, an excess of breakdown activity occurs. There are two main reasons for this: firstly some anti-protease enzymes (such as 1-antitrypsin) are inactivated by chemicals in cigarette smoke. Secondly, there is an excess number of enzyme-secreting white blood cells in the alveoli of smokers owing to frequent infections. Another possible factor in alveolar damage is the frequent coughing associated with the chronic bronchitis which often coexists with emphysema.



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## Lung cancer

This is also known as **bronchial carcinoma** since it primarily affects the epithelial cells of the bronchioles. It is one of the most common causes of death in Britain and across the developed world. In excess of 35 000 people die from lung cancer each year in Britain, with a male: female ratio of 3.5:1. Over 90 % of these people are regular smokers. Non-smokers who contract lung cancer are often people who have been exposed to carcinogenic substances such as asbestos, coal products and oil based products through their work.

Like other types of cancer, lung cancer is caused by harmful mutations in genes controlling cell division, cell growth, and cellular adhesion. Such mutations affect the production or functioning of normal regulatory proteins and hence lead to rapid and uncontrolled cell division and growth. In the case of lung cancer the rate of mutations in epithelium cells is increased by carcinogenic (cancer-causing) chemicals in cigarette smoke, especially the tar which is thought to contain many such carcinogens.

Mutant cells will continue to divide unchecked by normal processes which regulate mitosis, to form a tumour (mass of cancer cells). These tumours may manifest themselves in different ways, but commonly they ulcerate, destroying the surrounding tissue and leading to the coughing up of blood which causes the patient to consult a doctor. Sometimes the tumour will cause chest pain as it presses on other structures within the chest cavity, such as the ribs, diaphragm and pleural membrane, or it may block a bronchus or bronchiole leading to collapse of part of the lung. In other cases, however, a tumour may grow undetected within the lungs without obvious symptoms. This means that in many cases lung cancer is diagnosed too late for treatment by surgery to be possible.

A few cells may break off the main tumour and be carried via blood or lymphatics to a distant site to form a secondary cancer (**metastasis**). Common sites for lung cancer metastases are in bones, the liver and the brain. It is often these metastases which eventually kill the patient.

### ◆ CHECKPOINT SUMMARY

- ◆ Tar irritates the delicate epithelia of the respiratory system stimulating the production of mucus.
- ◆ Tar and mucus increase the diffusion distance, and reduce the surface area, for gaseous exchange in the alveoli.
- ◆ Chronic bronchitis is diagnosed if a chronic cough producing mucus persists for at least 3 months each year in two consecutive years.
- ◆ Emphysema is marked by the destruction of alveolar walls and the running together of alveoli to form larger air spaces, resulting in the reduction of the surface area for gaseous exchange. Airways collapse and breathing becomes laboured.
- ◆ Chronic bronchitis and emphysema are so closely linked that they are also known collectively as 'chronic obstructive pulmonary disease'.
- ◆ Both conditions are almost entirely due to cigarette smoking.
- ◆ Lung cancer (bronchial carcinoma) can remain symptomless to an advanced stage of development, but in other cases is characterised by chest pains, blocked airways leading to breathlessness.
- ◆ The break away of cancerous cells to form tumours at secondary sites (metastasis) is common feature of lung cancer.
- ◆ The risks associated with smoking apply to 'passive' smoking, albeit at a lower rate.

## EVALUATION of the EPIDEMIOLOGICAL and EXPERIMENTAL EVIDENCE LINKING CIGARETTE SMOKING to DISEASE and EARLY DEATH

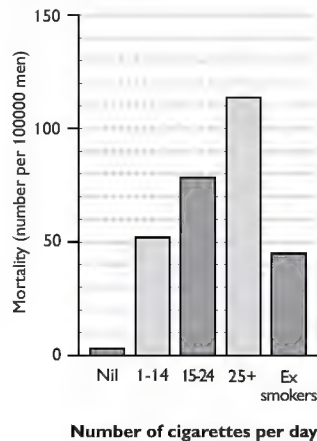
Epidemiological evidence is based on finding a statistically significant correlation between smoking and lung cancer using large numbers of people to generate enough data for statistical analysis (comparing, for example, observed and expected deaths across different groups). Any group of humans taken will differ in sex, age, exposure to environmental factors and genetic background, yet all of these differences need to be taken into account to ensure that just one factor is being investigated (this is the principle of the 'fair test', common to all scientific investigations.) However, it must be remembered, a statistically significant correlation does not prove a cause and effect relationship between the two factors. There can be a significant correlation between totally unrelated events.

Sir Richard Doll was responsible for demonstrating the strong links between smoking and lung cancer, chronic bronchitis and emphysema in a study which began in the 1950s. He used a technique known as the prospective study, where he identified his study group first and then recorded the deaths from smoking related diseases which occurred in members of the group over a number of years. His study population was male general practitioners (GPs) which was a particularly suitable choice: they were happy to be involved in a medical trial, were of broadly similar socio-economic groups, had similar lifestyles, occupations and exposures to other risk factors. Their main difference was in the numbers of cigarettes smoked per day: from 0 to over 30. In his study of 40 000 male GPs, Doll demonstrated that the risk of death from chronic bronchitis and emphysema in patients smoking more than 30 cigarettes per day was 20 times higher than that of non-smokers. The risk rose steadily with numbers of cigarettes smoked from 1-30 or more and was substantially decreased in ex-smokers. Further trials since then have backed up the original work.

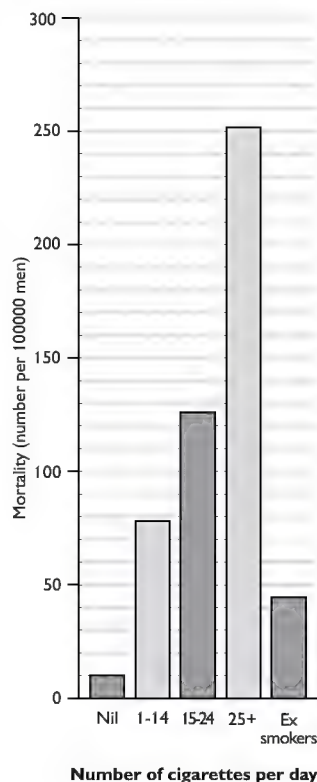
Similarly heavy smokers (more than 25 cigarettes per day) have a risk of lung cancer 25 times higher than non-smokers. Pipe smokers were at a lower risk, presumably because of lower amounts of inhalation.

Once a correlation is established, experimental evidence must be sought in order to establish a causal relationship e.g. smoking causes lung cancer. Such experiments invariably involve laboratory studies on experimental animals. Animal studies have shown that carcinogenic substances present in the tars can cause cancer when applied to the skin of mice. Further laboratory experiments have also shown that animals including mice and dogs can develop cancer of the larynx and lung from inhaling cigarette smoke. Whilst the links between smoking and lung cancer, bronchitis and emphysema are strikingly clear, they are still not appreciated by many people. Despite health education programmes, and the warnings which now appear on all cigarette packets and advertising material, smoking remains widespread. The British Government has set targets for a 30% reduction in smoking related diseases in men and a 15% reduction in women by 2010. It is essential that such programmes target young smokers since the earlier a person starts smoking, the greater is the risk of death from related illnesses.

Graph to show bronchitis death rates according to smoking habits



Graph to show death rates from lung cancer according to smoking habits



## SMOKING and CARDIOVASCULAR DISEASE

As described earlier, smoking significantly increases the risk of a number of diseases of the cardiovascular system namely hypertension, atherosclerosis and CHD. This may result in death from a heart attack or myocardial infarction, or stroke resulting from blockage of cerebral vessels by blood clots or thromboses. In fact, as many as 40% of all deaths from cardio-vascular disease are thought to be due to smoking. A heavy smoker (over 25 cigarettes per day) under the age of 45 years may increase his or her risk of heart disease by over 15 times compared to a non-smoker. Whilst there are clear correlations between numbers of cigarettes smoked and risk of such diseases, the exact causal mechanisms are not clear. The following effects have however been suggested.

### The effects of nicotine and carbon monoxide

**Nicotine** is the addictive component of cigarette smoke and has a number of effects on the cardiovascular system. It stimulates the release of adrenaline and noradrenaline; two hormones which increase blood pressure (hypertension) by causing the blood vessels to constrict, and heart rate and cardiac output to increase.

**Carbon monoxide** (CO) a colourless, odourless, poisonous gas found in tobacco smoke combines irreversibly with haemoglobin in red blood cells producing carboxyhaemoglobin. This compound cannot carry oxygen so the oxygen carrying capacity of the blood may be reduced by over 15% in heavy smokers. (The levels of the gas in the lungs of a smoker can be over eight times the level of carbon monoxide permitted in industry.)

### Atherosclerosis

Nicotine increases the concentration of fatty acids in the blood which may contribute to increasing deposition of atheroma leading to atherosclerosis. Carbon monoxide, along with nicotine, is also toxic to the endothelial lining of arteries and is thought to be one factor which may cause damage to this lining and allow cholesterol to enter the vessel wall causing development of atheromas.

### Coronary heart disease

The increased blood pressure (hypertension), heart rate and cardiac output, caused by nicotine, place extra strain on the heart and can be serious for the person who has already had a coronary attack or who is exposed to other risk factors for CHD, such as obesity or diabetes. Nicotine also makes the heart more irritable and can precipitate dangerous irregularities in heart beat. A lower rate of oxygen delivery to tissues as a result of the irreversible combination of carbon monoxide with haemoglobin may cause the heart rate and blood pressure to increase, which may be risk factors in cardiovascular disease. Also deficiencies of oxygen may cause angina and contribute towards a heart attack where insufficient oxygen is supplied to the heart muscle.

#### ◆ CHECKPOINT SUMMARY

- ◆ Epidemiological studies can be cross-sectional across all members of a particular group, or prospective (longitudinal), following a group of subjects over a long period of time.
- ◆ Sir Richard Doll's prospective study on male Doctors started in the 1950s first raised the correlation between smoking and bronchitis, emphysema and lung cancer.
- ◆ Correlation does not prove cause and effect. Two totally unrelated effects can be perfectly correlated.
- ◆ Despite the accumulating evidence, many still resist the conclusions.



Stroke

Nicotine also increases the likelihood of blood clotting within blood vessels which can lead to the development of blood clots or thromboses. This effect is mediated in several ways: nicotine and other components of tobacco smoke are thought to increase the 'stickiness' of blood platelets, the small cell fragments involved in normal blood clotting, causing them to adhere to the surfaces of damaged atheromatous areas. At the same time more fibrinogen (one of the proteins involved in blood clotting) is produced while lower levels of enzymes which break down blood clots are found. Blood clots formed in the coronary arteries may block the artery leading to a myocardial infarction or heart attack. Alternatively the clot may be dislodged and travel in the blood (as an embolus) to the brain where it may block a cerebral vessel, depriving part of the brain of oxygen and causing a stroke.

Learning Objectives (1)

GLOBAL DISTRIBUTION of CORONARY HEART DISEASE (CHD)

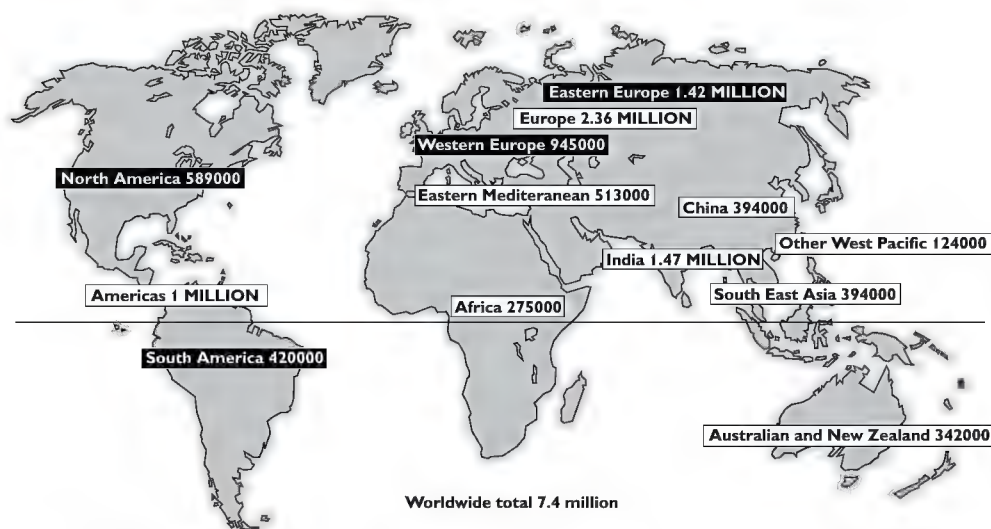
In 1999 it is estimated that all cardiovascular diseases, including Coronary Heart Disease (CHD), killed 16.7 million people worldwide. In common with other non-infectious diseases, CHD is more common in developed countries compared to developing countries. This statement, however, masks the fact that CHD is becoming very common in many developing countries, particularly in urban regions. Up to 25% of deaths in those aged 50-65 in developing countries are from CHD, with 1.47 million people dying of CHD in India alone in 1999, a figure which is expected to double within the next 20 years. On the other hand, many developed countries such as France, and Japan have very low death rates from CHD. It should also be noted that whilst CHD is currently one of the main causes of death in developed countries, in many of these, including England and the United States, the rate has been declining since the 1970s.

CHD is closely associated with the changes in lifestyle which accompany urbanisation and increased affluence. These include increased food intake particularly of saturated fat, sugar, alcohol and salt in the diet, decreased physical activity due to more sedentary occupations and the high level of car ownership. Increased cigarette smoking and increased mental stress are other important factors. It is also associated with old age, so wherever life expectancy increases so too does the rate of CHD.

In addition to the recognised risk factors there seem to be other subtle genetic and environmental differences between ethnic groups which are also significant. This may explain why the risk of CHD is greater in those of Indian origin living in the UK compared to that of Caucasians (whites), even when lifestyle differences are taken into account.

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#### Global distribution of deaths from Coronary Heart Disease (CHD) 1999



Learning Objective 17

### **CORONARY HEART DISEASE: The BALANCE between PREVENTION and CURE**

#### **Prevention**

Prevention is always better than cure. As the risk factors for the development of CHD are becoming clearer, there are many recommended ways by which individuals can reduce their own risk of developing the disease. Such preventative measures should be put into action early in life since there is evidence that atheroma build-up may begin in childhood when bad dietary habits, insufficient exercise, and smoking often begin. Schools and other community institutions need to increase the emphasis on healthy lifestyle, as do general practitioners and other health professionals. Basic measures to prevent or rather reduce the risk of CHD include:

- ▼ Never starting to smoke or stopping if a smoker.
- ▼ Reducing the amount of saturated fat in the diet and the overall number of calories eaten. Ideally less than 30% of calories taken should come from fats.
- ▼ Losing weight so that body mass index (BMI Section 5.2.2) is below 25.
- ▼ Reducing salt intake which reduces the volume of the body fluids.
- ▼ Increasing the amount of exercise taken to a minimum of three twenty minute sessions per week. These can include gentle exercise such as walking but in young people should involve more vigorous exercise.

The above list of preventive measures may be taken by all individuals whatever their age or current risk of CHD. Such measures will also help to lower the risk of CHD in individuals who have put themselves at high risk through smoking and other activities. It should be noted that changes of lifestyle aimed at preventing CHD can have a range of other health benefits to the individual and to society as a whole. Thus reducing smoking will also reduce the risk of respiratory diseases and many cancers, while increasing exercise levels and losing weight may increase the mental well being and confidence of an individual.

Under medical supervision additional measures might be appropriate for high risk groups. Medical evidence is emerging that those at risk of CHD might benefit from taking small amounts of aspirin each day to reduce the risk of blood clotting and hence the development of thromboses.

## Cure

Cure or treatment of those patients who have already developed CHD involves a range of treatments.

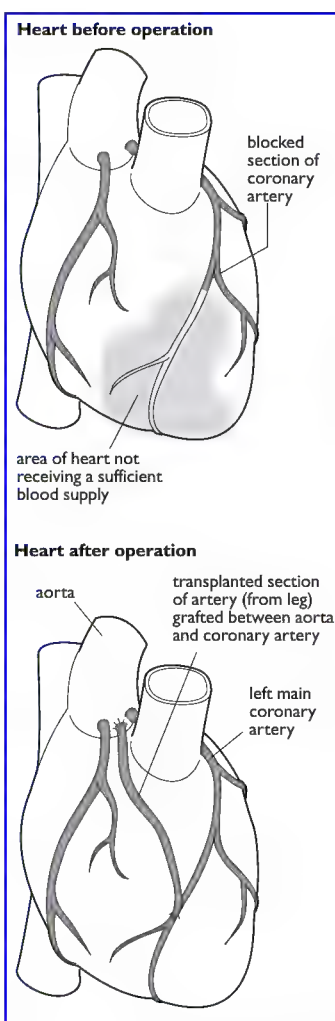
**Drug therapy** of which there are three main classes: nitrates which dilate coronary arteries, calcium antagonists which dilate coronary and peripheral arteries and reduce oxygen consumption by the heart, and beta-blockers which reduce cardiac output by lowering the heart rate and the force of contraction of the heart muscle.

**Coronary by-pass surgery** is suitable for a small proportion of patients with CHD. This involves by-passing the narrowings of the coronary arteries using pieces of artery or vein taken from elsewhere in the patient's body, restoring a blood supply to the deficient region. The piece of vessel is grafted onto a healthy artery (often the aorta) at one end and onto the damaged artery downstream of the blockage at the other, diverting the blood around the blockage and restoring blood supply to the heart muscle. Sometimes more than one artery may be by-passed at a time, hence the terms double and triple by-pass. One advantage of using a piece of blood vessel from a patient's own body in this operation is that it avoids rejection of the tissue.

Currently over 20 000 by-pass operations are performed in Britain each year, but this figure is lower than in some other countries and the Government is aiming to increase the number in a new bid to cut deaths from heart disease and stroke.

**Heart transplant surgery** was first performed in 1969. It involves the removal of the diseased heart of an individual (the recipient) and its replacement with a healthy heart from a donor who is brain stem dead. The donor heart is connected to the blood vessels of the recipient, although the recipient's right atrium, containing the sino-atrial node (pacemaker) is usually retained to initiate the heart beat (see 5.3.2).

Heart transplants are major surgical procedures which carry a risk of death associated with the surgery itself of between 10-20%. and are only performed as a last resort. They may, however, offer the only hope of recovery from many types of heart disease, including some congenital defects in children, as well as for a very small number of patients suffering from CHD. 60% of patients now survive for at least five years after a heart transplant, many leading active lives.



In all cases it is necessary to find a heart with a suitable 'tissue type' (having cells with similar surface antigens to those of the recipient) to prevent rejection of the organ by the immune system of the patient. This occurs because the cells of the transplanted heart are recognised as foreign by T-lymphocytes within the blood stream and attacked by them. Immuno-suppressant drugs are given to reduce this problem, but inevitably they increase the risk of infection.

Whilst heart surgery (particularly by-pass grafts) may cure some individuals of life threatening heart disease and allow them many years of good health, in other cases the benefits of these expensive procedures can be short lived. Individuals who have previously had a high-risk lifestyle in terms of CHD, for example through smoking, high fat diets and lack of exercise, may in some cases, return to their former habits after surgery. Thus by-pass grafts themselves may become narrowed through atheroma build up leading to further angina and myocardial infarction, especially in smokers. There are many ethical and financial issues involved here, particularly when health services are under financial pressure and only limited numbers of operations can be performed.

It could be argued that patients due for heart surgery must make life-style changes before their surgery and maintain these afterwards. A particular focus should be on giving up smoking, losing weight and taking more exercise. A more extreme view is that priority surgery be given to those individuals who have taken preventative measures, but who have still developed CHD (perhaps those who have juvenile diabetes which has led them to develop hypertension, or those who have a genetic predisposition to high levels of blood cholesterol). Others argue that organ donors or their families should be able to choose the type of person (e.g. a non-smoker) to whom an organ should be given, or suggest that patients should contribute towards the cost of hospital treatment for 'self-inflicted' diseases. Due to shortage of hearts and other organs there is also the controversial issue as to whether organ donation should operate on an 'opt out' policy rather than the current 'opt in' system.

Whilst some of these positions are extreme and are not yet practised in the health service they do raise the question of an individual's responsibility for his or her own health. This is particularly true where preventative measures are well known and can be followed relatively easily.

#### ◆ CHECKPOINT SUMMARY

- ◆ Nicotine is the addictive drug in tobacco smoke.
- ◆ Nicotine stimulates the release of adrenaline and noradrenaline, which in turn result in high blood pressure, increased heart rate and cardiac output.
- ◆ Nicotine increases the levels of fatty acids in the plasma of the blood, damages the lining of blood vessels, leading to atheroma and atherosclerosis.
- ◆ Nicotine increases the tendency for the blood to clot, and hence the formation of internal clots (thromboses).
- ◆ Tobacco smoking is the major cause of leg amputation in the UK, as a result of atherosclerosis and thrombosis in the legs.
- ◆ Nicotine causes dangerous irregularities in the electrical activity of the heart.
- ◆ Carbon monoxide combines irreversibly with haemoglobin preventing its ability to deliver oxygen to the tissues.
- ◆ The combined effects of tobacco smoking greatly increases the risks of all cardiovascular disease.
- ◆ Coronary heart disease (CHD) is more common in developed countries, although exceptions exist such as France and Japan.
- ◆ CHD is closely associated with the changes in lifestyle which accompany urbanisation and increased affluence.
- ◆ Prevention is always better than cure, measures include non-smoking, reducing dietary saturated fats, keeping the BMI below 25, reducing salt intake, and increasing the amount of aerobic exercise.
- ◆ Cure involves drug therapy, coronary by-pass surgery and heart transplants.

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## 2.5

# Infectious Diseases

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### Content

- ▼ Cholera, malaria, tuberculosis (TB) and AIDS
- ▼ Antibiotics

#### Learning Objectives

Candidates should be able to:

- a) describe the causes and means of transmission of cholera, malaria, AIDS/HIV and TB. (Knowledge of the symptoms of these diseases is not required)
- b) assess the worldwide importance of these diseases.
- c) describe the roles of social, economic and biological factors in the prevention and control of these diseases.
- d) outline the role of antibiotics in the treatment of infectious disease.

#### Learning Objectives (Light & TB)

**CAUSES and MEANS OF TRANSMISSION of CHOLERA, MALARIA, AIDS/HIV and TB, their WORLDWIDE IMPORTANCE, and the ROLES of SOCIAL, ECONOMIC and BIOLOGICAL FACTORS in the PREVENTION and CONTROL of these DISEASES**

### Introduction

Infectious diseases are diseases caused by pathogens (mainly bacteria, viruses, fungi and protoctists) which can be transmitted from one person to another in a variety of ways. The four diseases mentioned above, cholera, malaria, tuberculosis and HIV/AIDS, have all proved very difficult to prevent and control and there is very little chance of any of them being eradicated in the foreseeable future. There are many reasons for this, which include biological features of the pathogens themselves, as well as social and economic conditions of the human populations who suffer from them.

Reducing the number of deaths from each of these diseases involves a range of strategies which include modern medical treatments as well as simple improvements in living conditions, sanitation and education. In all cases there are two primary aims which are often closely linked. Firstly it is important to prevent people from becoming infected in the beginning (**disease prevention**). Secondly those who do catch the diseases must be managed and treated to ensure that the diseases do not spread through the population and cause epidemics. This is known as **disease control**.

Worldwide importance of infectious diseases

World-wide, infectious diseases cause 25% of all deaths, and are the most important causes of death in children and young adults (13 million deaths per year). In many countries especially in Africa they represent over 80% of all deaths. WHO estimates for 1999 show, for example, over 3.5 million deaths world-wide from respiratory infections (excluding tuberculosis), 1.5 million deaths from tuberculosis (TB), over 2 million from diarrhoeal diseases including cholera, 1.2 million from malaria and 2.6 million from HIV/AIDS. In addition to the deaths, such diseases also cause serious illness in thousands of millions of other people.

The majority of these deaths now occur in the developing world, yet less than a century ago infectious diseases, especially TB, were also the most common causes of death in Britain and other European countries. In the past fifteen years, however, the appearance of HIV, the dramatic resurgence (increase after a previous decline) in cases of TB and the appearance of antibiotic resistant bacteria (including some strains of those causing TB), has demonstrated that infectious diseases are still a threat to health in the developed world. Air travel and increasing population movements also bring risk of infectious diseases to more people in the developed world.

Table of mortality statistics from 1999: Africa, containing many of the poorest 'developing' countries compared to Europe, containing some of the wealthiest 'developed' countries

|                             | Africa           | Western Europe |
|-----------------------------|------------------|----------------|
| Total Pop                   | 600 000 000      | 392 000 000    |
| Cause of death              |                  |                |
| All non-infectious diseases | 2 100 000 (21.9) | 3 499 000 (88) |
| All infectious diseases     | 4 600 000 (47.9) | 51 000 (1.3)   |
| HIV/AIDS                    | 1 800 000 (18.7) | 12 000 (0.3)   |
| Respiratory infections      | 806 000 (8.3)    | 155 000 (3.9)  |
| Diarrhoeal diseases         | 731 000 (7.6)    | 4000 (0.1)     |
| Tuberculosis                | 209 000 (2.2)    | 7000 (0.2)     |
| Malaria                     | 961 000 (10.0)   | none           |
| Total deaths                | 9 600 000        | 3 974 000      |

All figures in thousands  
Percentage of Total deaths in brackets

Cholera

**Cause** - Cholera, a disease characterised by severe diarrhoea and death from dehydration, is caused by the bacterium *Vibrio cholerae*. Whilst it was once common in Britain and across the world it is now mainly found in the poor developing countries and particularly in overcrowded regions within these countries. It is a major cause of death and illness in these regions, often occurring in epidemics. It is estimated that around 6 million cholera infections occur per year, worldwide, with at least 120 000 deaths.

**Transmission** is usually via drinking water or food which is contaminated with infected faeces containing the cholera bacteria.

This means of transmission is sometimes known as the **faeco-oral route**. Flies which land on infected faeces and then on foodstuffs can also spread the disease. In addition, cholera may be spread by eating shellfish which have lived in contaminated water.

Owing to its mode of transmission, cholera may spread extremely rapidly from one infected person to hundreds of others. This spread does, however, rely on poor sanitation, including a lack of toilet facilities and an absence of clean drinking water. Unfortunately such conditions still exist in many developing countries, where sewage enters the same rivers or streams which are used to bathe in and drink from. These conditions are made worse in the slums of large cities such as Calcutta in India, and Sao Paulo in Brazil, in makeshift camps following disruption by famine, war or natural disasters, and when large groups of people come together for religious festivals or other celebrations. Recent epidemic outbreaks have occurred, for example, in the Peruvian shanty town of Belén in 1991 (during a larger cholera epidemic in Peru) and in the refugee camps during the Rwandan crisis of 1994.

**Prevention and control** is mainly by improving sanitation and reduce overcrowding. Chlorination of water, the provision of piped water, of latrines (toilets) and sewage treatment facilities can lead to drastic reductions in the number of cases of cholera. Measures to reduce flies which can transmit the disease from faeces to food are also important.

Education is also crucial to ensure that people understand and practise basic hygiene. In particular it is vital that the link between faeces and disease is clear. People should be encouraged, for example, to wash their hands after using the toilet, to boil water before drinking it and to avoid defaecation in or near streams and rivers.

Yet although these measures may sound simple, the provision of adequate sanitation systems is very expensive. Countries must often rely on overseas money (aid) to pay for these and for the education programmes which can be difficult to implement.

In addition to these measures a cholera vaccine is available. Whilst this is useful for people travelling to areas where cholera is endemic and for use in such regions during epidemics it is not very effective and it only last a few months. It is hoped that a new, genetically engineered vaccine using a live attenuated (weakened) bacterium with two of its toxin genes deleted will prove more effective.

Once people are infected with cholera the disease can be controlled in a number of ways if medical facilities are available. Patients and their close contacts (family members or work colleagues) may be treated with antibiotics or given vaccinations. Patients should also be closely monitored and have their faeces disposed of in a hygienic fashion. Oral rehydration therapy, the provision of water mixed with appropriate quantities of salts and sugars, to replace lost fluids, is very effective in treating the disease.

## Malaria

**Cause** - Malaria is caused by a single celled parasite, *Plasmodium*, which invades the liver cells and red blood cells of humans. There are four species which affect humans, but the most common are *Plasmodium vivax* which usually causes a relatively mild infection, and the virulent *Plasmodium falciparum* which is responsible for most malaria deaths. Although some areas which previously experienced malaria are now free of the disease (such as the United States and parts of Europe) one third of the world's population still lives in malarious regions. The disease is particularly severe in sub-Saharan Africa, where in parts, up to a quarter of children die of the disease, and almost everyone becomes infected several times during their lives. Over 1 million people died of the disease worldwide in 1999.

**Transmission** from one person to another is by the bite of an infected female *Anopheles* mosquito (the vector). As shown in the diagram below, the mosquito is not simply a passive carrier of the disease: the malarial parasite must complete part of its life cycle in humans and part inside the female mosquito.

A malaria infection of a human starts when a female mosquito injects malaria parasites known as **sporozoites** in its anti-coagulant saliva into a human on which it is feeding. These parasites migrate to the liver cells where they reproduce **asexually**, and develop into merozoites which then infect red blood cells. Here they also reproduce asexually, producing huge numbers of additional merozoites which burst out of the red blood cells and cause the characteristic fever and other symptoms of the disease. Some merozoites develop into gametocytes which can be taken up when another female mosquito feeds on the infected person's blood. Once inside the body of the mosquito these gametocytes fuse, the resulting zygotes develop into sporozoites and move into the salivary glands of the female mosquito where they can be injected into another person. The cycle thus begins again.

### Worldwide distribution of malaria

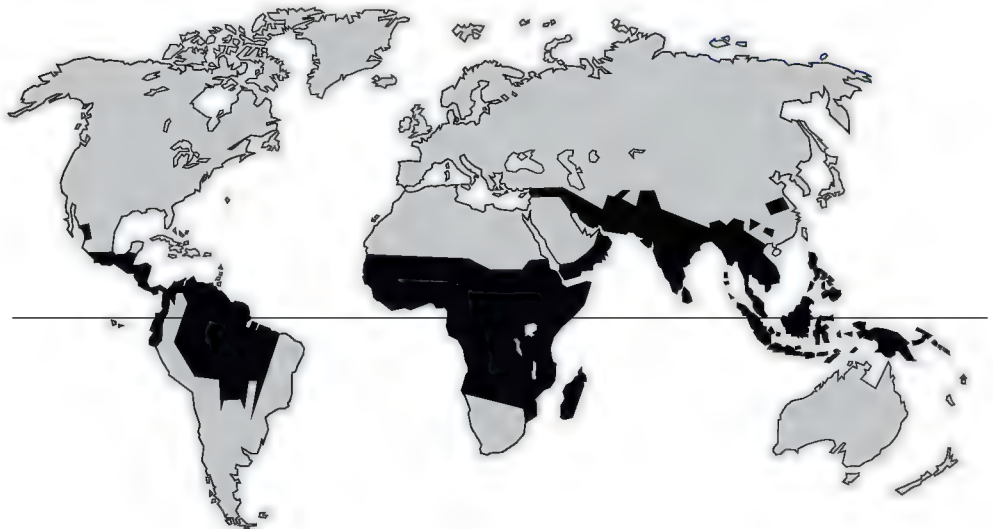
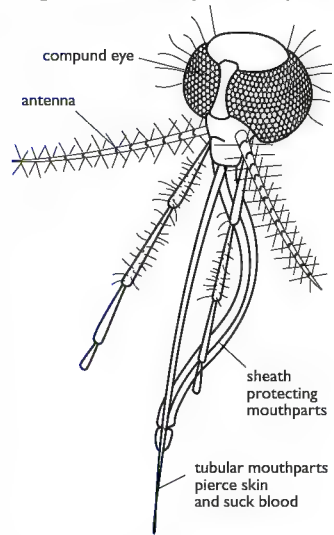
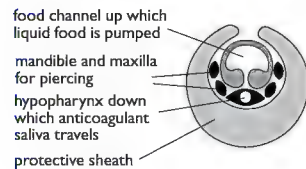


Diagram to show mosquito mouthparts

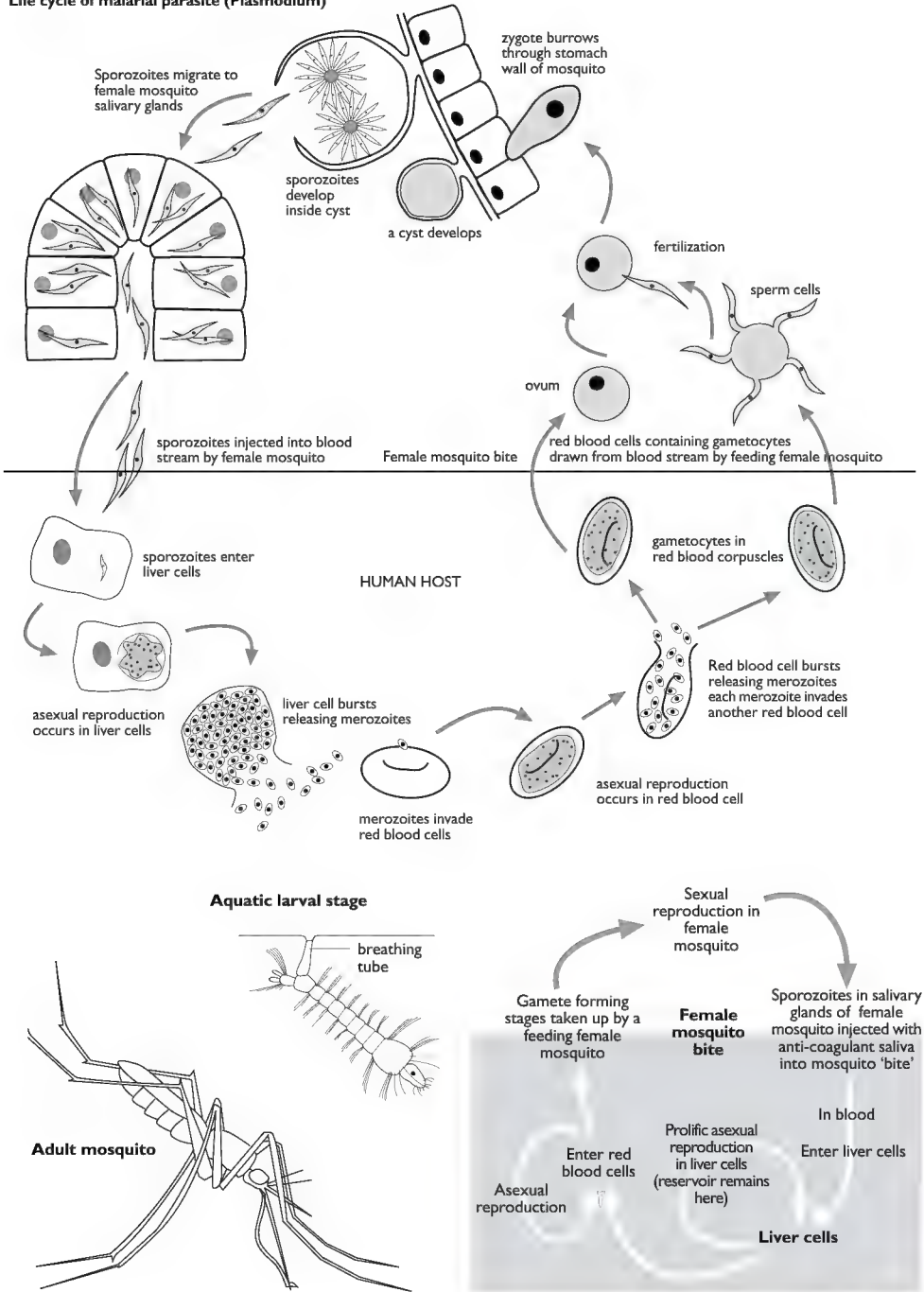


Section through mouthparts





**Life cycle of malarial parasite (Plasmodium)**



**Prevention and control** is mainly by reducing the risk of mosquito bites and measures include:

- ▼ Drainage of marshy areas and removal, where possible, of any exposed areas of water, including puddles, disused cattle troughs, old tyres etc., to prevent mosquitoes breeding (the female mosquito lays her eggs in water and the larvae and pupae are aquatic but air breathing).
- ▼ Placing oil on the surface of water which prevents mosquito larvae and pupae from obtaining oxygen and hence causes their death.
- ▼ Killing the mosquito vector with insecticides and/or killing the larvae with larvicides.
- ▼ Using biological control in the form of fish which eat mosquito larvae in the water
- ▼ Encouraging people to protect themselves from being bitten by female mosquitoes by sleeping under bed nets, wearing protective clothing and using insecticide sprays and repellants.

In addition, anti-malarial drugs and the plants from which they are derived, which inhibit the growth of the malaria parasite inside humans have been used for hundreds of years. These include quinine and synthetic drugs such as chloroquine and mefloquine. There is, as yet, no effective malaria vaccine.

Anti-malarial drugs may be used as prophylaxis (to prevent disease occurring by taking the drug in advance of exposure to malaria) as is done in some community prevention programmes, or as treatment following infection. Such drugs can thus form an important means of controlling the disease in individuals who are infected, improving their condition and reducing the likelihood of the disease being passed onto others. It is also important to ensure that infected individuals have access to medical facilities (including transport to treatment centres) and sufficient education to recognise the symptoms of malaria and to seek help early.

Whilst there are many measures available for the prevention and control of malaria, these are not always successful. By the 1950s drainage measures and the use of the insecticide DDT had eliminated malaria from parts of the United States and Europe but these had less impact in tropical regions of the developing world. There are many reasons for failure which include:

- ▼ Mosquitoes breed in the tiniest bodies of water, so even if swamps are drained the insects will exploit puddles, flower pots or even hoof-prints with a few millimetres of water.
- ▼ Expense and logistical difficulties have hindered mosquito control programmes. To be effective they must reach all areas of a country, yet often poor roads, mountainous terrain and civil unrest prevent access to some regions. Since mosquitoes can fly and travel distances of several kilometres any control campaign must be carried out on both sides of national boundaries.
- ▼ Mosquitoes developed resistance to DDT as a result of a gene mutation. This spread rapidly through mosquito populations due to their short generation time and large reproductive potential, rendering the insecticide ineffective by the late 1960s.
- ▼ Similarly malaria parasites developed resistance to anti-malarial drugs, especially chloroquine. Chloroquine resistance was first noted in the 1970s in South East Asia but has now spread throughout Asia and Africa. Resistance has developed to many other anti-malarial drugs and there are regions where no anti-malarial drugs are effective.

#### ◆ CHECKPOINT SUMMARY

- ◆ Malaria is caused by the single celled parasite (*Plasmodium*) and transmitted via a female mosquito vector (*Anopheles*).
- ◆ Malaria causes over 1 million deaths per year, primarily in sub-Saharan Africa, and other parts of the developing world. It was once common in the United States and parts of Europe.
- ◆ The malaria parasite lifecycle is complex and involves a sexual stage in the female mosquito and asexual stages in the liver and red blood cells of humans.
- ◆ A human can only become infected with malaria when an infected female mosquito feeds on their blood. In turn a female mosquito can only become infected if it takes a blood meal from an infected person.
- ◆ Malaria prevention and control is focused on preventing people being bitten by mosquitoes. This includes individual protective measures as well as regional, national or international efforts to control mosquitoes.
- ◆ Malaria prevention and control also uses various anti-malarial drugs. There is no vaccine.
- ◆ There are biological, economic and political reasons why malaria control is difficult.
- ◆ Biological reasons include the fact that malaria parasites acquired resistance to anti-malarial drugs, that mosquitoes acquired resistance to DDT, and that mosquitoes need only tiny amounts of water to breed.
- ◆ Malaria control is very expensive and needs years of sustained international effort and cooperation. This has often proved difficult.

Tuberculosis

**Cause** - Tuberculosis or TB is primarily a disease of the lungs and respiratory tract and is caused by a bacterium called *Mycobacterium tuberculosis*. The bacterium multiplies in and destroys the lung tissue. It also suppresses the immune system making it harder for the body of an infected person to make an immune response against the disease. It can also infect other parts of the body, including the bones, gut and kidneys.

The World Health Organisation estimates that over 1.5 million people died of TB worldwide in 1999, with several times that number being infected with the disease. The majority of these sufferers are in the developing world, but the disease is also becoming increasingly common again in Europe and the United States where it was once a leading cause of death. There were, for example, 7000 deaths in Western Europe in 1999, an enormous increase over figures from as recently as 10 years ago.

**Transmission** of TB is by airborne or droplet infection, which means that it is transmitted from one person to another via microscopic infectious water droplets in the air. When a person infected with TB coughs, he or she releases thousands of such droplets containing bacteria which may be breathed in by other people who are close by. Usually, however, a person needs prolonged contact with an infected person to develop the disease: it is not as infectious as the common cold or influenza.

TB is most easily spread, and hence most common, where people live or work in crowded conditions where there is little fresh air. Unfortunately such conditions are frequently found in the poorer regions of cities of the developing world, in refugee camps, in prisons, and in dormitories or centres for the homeless which are becoming increasingly common in the developed world.

TB is much more likely to cause disease in people whose immune systems have been weakened by infections with other diseases (especially HIV - see below) or through malnutrition. Such conditions are more common in the circumstances of poverty, war or social disadvantage.

Another form of TB, *Mycobacterium bovis*, can be spread through unpasteurised milk and milk products.

**Prevention and control** of TB is best achieved by preventing the bacterium from spreading, by improving living and working conditions of the population. Measures include:

- ▼ Reducing overcrowding in homes and workplaces.
- ▼ Improving ventilation in buildings so that fresh air can circulate. This also includes reducing the amount of smoke or dust in the atmosphere as inhalation of such particles can inflame the lungs and make them more susceptible to infection with TB.
- ▼ Improving the overall health and nutrition of the population to ensure that the immune system is fully functional.

It was a combination of these measures which lead to dramatic reductions in deaths from the disease in Britain even before the tuberculosis bacterium was discovered in 1882. Later, when the cause of the disease and its mode of transmission were understood, infected people were isolated to prevent spread.

A TB vaccine, known as BCG (Bacille Calmette Guerin after the scientists who developed it, using an attenuated (weakened) strain of bacterium, in the 1920s) has been used extensively since 1954. Although this vaccine is widely used in the developing and developed world, it does not offer 100% protection against TB. It is only effective in those who have not been exposed to the bacterium before and its effectiveness seems to vary considerably between populations.

Control of TB in infected people is heavily reliant on antibiotics, which have been available since the 1940s. In addition to treating infected people, control programmes often aim to find and test contacts of these people for TB infection and, if necessary, treat them as well. Yet, in spite of decades of effective treatment by antibiotics, many strains of TB bacteria are now resistant to such drugs. Some strains are known as multi drug resistant-TB (MDR-TB) and are effectively untreatable. One reason for this is thought to be the fact that the cure of TB requires very long courses (up to 12 months) of a combination of antibiotics. Often patients prescribed such long courses will fail to complete them because the drugs have unpleasant side effects or because people move away from the area and fail to attend clinics. This increases the chance of bacterial resistance developing to some or all of these antibiotics (see section on antibiotics). Once such dangerous strains emerge they can then be passed on to other people and spread through the population. Other factors are increasing population density, especially in cities, increasing poverty, declining living conditions, including increased homelessness, and the rise of HIV/AIDS.

- ▼ Tuberculosis (TB) is caused by a bacterium (*Mycobacterium tuberculosis*) which infects the lung and other tissues.
- ▼ TB currently kills over 1.5 million people per year. Most of these deaths are in the developing countries but its frequency is increasing across the world.
- ▼ The disease is spread via droplets in the air, and hence is spread most rapidly in overcrowded, underventilated areas.

#### ◆ CHECKPOINT SUMMARY

- ◆ Prevention of TB is focused on improving living and working conditions and improving the overall nutrition and health of individuals. A vaccine is also available but is not effective in all cases.
- ◆ Control of TB in infected patients relies on long courses of antibiotics. Often a combination of antibiotics is taken.
- ◆ Two of the reasons for increases in TB cases and deaths in the past decade have been the emergence of antibiotic resistant strains of TB and the rise of HIV/AIDS which increases susceptibility.

## HIV/AIDS

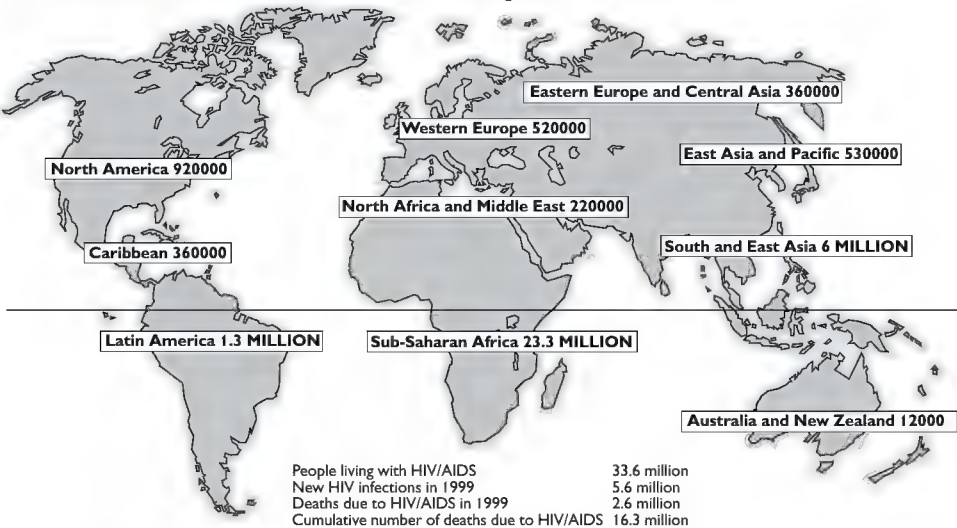
**Cause** - Acquired Immune Deficiency Syndrome (AIDS) results from infection with the Human Immunodeficiency Virus (HIV). There are two types of this virus known as HIV-I and HIV-II. The former is more virulent and responsible for most AIDS deaths. As its name suggests, AIDS is a disorder where the body's immune system is damaged preventing it from fighting common infections. This happens because the HIV virus lives and replicates inside **Helper T-lymphocytes** and prevents them from 'helping' B and T lymphocytes to work (section 5.2.6). Not all people infected with the HIV virus (HIV antibody positive people) go on to develop AIDS although the vast majority do. The period of time between infection and development of AIDS is highly variable (from 2 to 15 years), but once AIDS is diagnosed, death from infectious diseases, especially pneumonia and TB, or from a range of cancers will eventually occur.

AIDS was not recognised as a disease until the early 1980s, but has spread rapidly since that time. It is now regarded as a **pandemic**. It is estimated that at least 33 million people are infected with HIV today. The continent most affected at present is Africa, where 70%

of HIV cases are found, but the number of cases in Asia, is increasing rapidly. Over 2.6 million deaths per year now result from the disease, which are concentrated in young heterosexual people in the developing world. However, the importance of the disease in the developed world should not be overlooked. HIV/AIDS has taken the developed world by surprise, proving that new and deadly infectious diseases can still emerge.

The significance of the AIDS pandemic extends far beyond the simple tally of deaths resulting from the disease. Firstly, many of its victims are young adults. Some experts have suggested that this could result in a reduced workforce in some areas leading to a slowing of economic progress. Future population growth may also be affected. Secondly, the rise of HIV/AIDS and its effects on the immune system have led to a resurgence of TB and other infectious diseases. Once such diseases gain a foothold in AIDS patients they can then be transmitted to other people in the community. Thirdly, HIV/AIDS kills people slowly, meaning that they often require hospital treatment for many years. With so many new cases, and not enough money for medical services, it is possible that spending on other diseases such as malaria will be reduced, causing more deaths from these and other causes.

Worldwide distribution of adults and children estimated to be living with HIV/AIDS 1999,



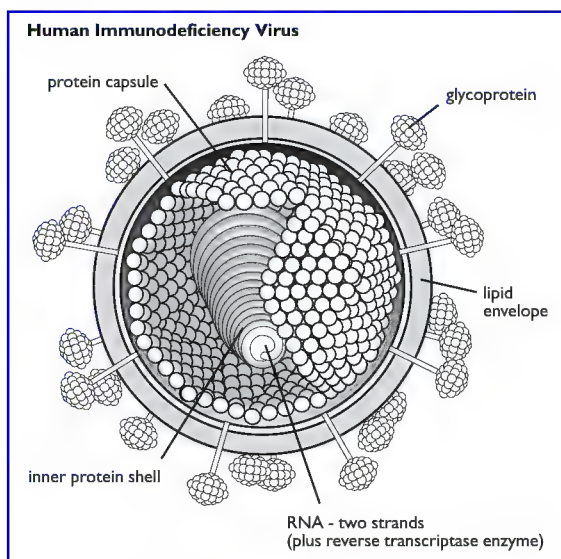
**Transmission** occurs in several ways all of which involve a direct exchange of body fluids between an HIV infected person and an uninfected recipient. There are no recorded instances of transmission via saliva or sweat. The main modes of transmission are:

**Sexual contact.** 90% of people with HIV have caught it through vaginal or anal intercourse or oral sex with infected people. This relies on infected semen or vaginal fluid entering the blood stream of a recipient, often through cuts or sores. Heterosexual activity is most significant in terms of overall numbers of HIV infections transmitted but anal intercourse carries a higher risk of infection as the rectum is easily torn.

**Blood contact.** HIV infected blood may enter the bloodstream via needles used for intravenous(injected) drugs, from transfusions of blood or blood products, or during a range of medical procedures such as vaccinations.

**Mother to child.** HIV may pass from mother to fetus via the placenta, from mother to baby at birth when blood contact may occur or during breast feeding. HIV-II is more commonly transmitted in this way.

**Prevention and Control** involves a range of procedures to prevent transmission of infected body fluids. Since most HIV cases arise from sexual contact, one of the most important ways of preventing



further spread is through programmes emphasising 'safe sex'. Educating people about HIV/AIDS, and encouraging them to avoid casual sexual contact, reduce the number of sexual partners and use **condoms** all markedly reduce the risk of catching HIV. Such programmes are in place across the world, but following their advice does require changes in social behaviour. Many people are reluctant to talk about sexual behaviour (or sexually transmitted diseases) and are also reluctant to use condoms, even if they are provided free. In some areas, however, condoms are not available, or are expensive to buy, whilst in other regions religious beliefs may inhibit the use of contraceptives.

The fact that carriers of the disease may transmit it for years before they know they are infected further hinders preventative measures. Even when an HIV test is taken it is not 100% accurate, especially during the early stages of infection where it may give a false negative result. Also many people who suspect that they are infected will not seek such a test as they know there is no cure if they are HIV positive. In developed countries, those known to be HIV positive will be monitored for signs of AIDS and treated if these symptoms

#### ◆ CHECKPOINT SUMMARY

- ◆ Cholera is caused by a bacterium and mainly spread through infected water and food.
- ◆ Cholera was once common in Europe but is now mainly restricted to the developing world where it causes over 100 000 deaths per year.
- ◆ Cholera spreads extremely rapidly where overcrowded conditions and poor sanitation occur: epidemics often occur in shanty towns, refugee camps and during large gatherings.
- ◆ The most effective way of preventing cholera is through improving sanitation and education about basic hygiene. A vaccine is available but is of limited value.
- ◆ Control of cholera can involve antibiotic treatment of sufferers and close contacts and isolation of cases.

develop. They are offered advice and counselling to allow them to come to terms with the disease and prevent them from infecting other people. Contacts of HIV positive people will often be traced in attempts to prevent further spread. In developing countries such services (including HIV tests) may not always be available.

To prevent the spread of HIV through blood and blood products Western countries have developed strict screening procedures. All blood used in transfusions, or for the extraction of products is now guaranteed to be free of HIV. Needles used for injections in hospitals and surgeries are sterile and are thrown away after one use. Drug addicts in many countries, including the UK, may be provided with free sterile needles and syringes. Unfortunately, due to lack of money and technology, and urgent demand for medical services, many developing countries do not have these controls. This means that HIV is still transmitted via blood transfusions, during routine hospital procedures, and even during vaccination programmes.

Drugs are now available to prolong the lives of AIDS sufferers, but the disease is currently incurable. There is, as yet, no vaccine against HIV. The main reason why development of a vaccine is difficult is that the virus is continually changing its surface antigens, making it hard for antibodies to recognise it and initiate mechanisms for its destruction before it enters the T cells. Furthermore, with such a dangerous virus there is concern over safety of the vaccine itself.

## The ROLE of ANTIBIOTICS in the TREATMENT of INFECTIOUS DISEASE

An **antibiotic** is a molecule produced by one type of microorganism which is capable of destroying or inhibiting the growth of another type of microorganism. Most commonly they are chemicals produced naturally by fungi or bacteria which destroy other bacteria. Antibiotics work in several ways but they are often divided into two main categories: those which kill bacteria are called **bactericidal** antibiotics, whilst those which inhibit their growth are known as **bacteriostatic** antibiotics.

Today some antibiotics can be synthesised (made artificially) in laboratories, using the blueprint of natural molecules. Others are produced on a massive scale in fermenters which may use naturally occurring or genetically engineered microorganisms. In both cases production is highly efficient and cheap once the system is running.

The discovery of antibiotics was one of the most significant events in medical history. It was in 1928 that Alexander Fleming first noticed that the mould *Penicillium notatum* prevented the growth of bacteria on agar plates. Eleven years later, Ernst Chain and Howard Florey purified the antibiotic penicillin and tested it in mice with bacterial infections. By the mid-1940s several other antibiotics had been discovered and were being tested on human infections. Antibiotics were found to be extraordinarily efficient at killing bacteria and allowed the first effective cures for fatal diseases like syphilis and tuberculosis. They revolutionised the treatment of a wide variety of bacterial infections and have played a major role in preventing illness and death across the world. Many infections which we

### ◆ CHECKPOINT SUMMARY

- ◆ HIV/AIDS is caused by the HIV virus.
- ◆ AIDS is a disorder in which the body's immune system is gradually destroyed (by invasion and destruction of helper T-lymphocytes) leading to death from a range of infectious diseases.
- ◆ HIV/AIDS is a pandemic: 33 million people are affected with 2.6 million deaths in 1999.
- ◆ HIV virus is transmitted in three main ways: sexual contact, blood contact and from mother to child. Sexual contact is the most significant.
- ◆ HIV transmission can be reduced or prevented by changes in sexual behaviour; especially the use of condoms.
- ◆ Screening of blood products and use of sterile medical equipment prevents HIV spread in hospitals and other settings.
- ◆ There is, as yet, no HIV vaccine.
- ◆ Education about HIV/AIDS is critical in preventing further spread. The fact that the disease is sexually transmitted can make this more difficult. Counselling of people diagnosed as HIV positive (via HIV tests) is equally important in disease control.
- ◆ Differences in the availability of condoms, in adequate medical facilities and in education can help to explain why HIV/AIDS is spreading more rapidly in developing countries.
- ◆ Most new HIV/AIDS cases are in young heterosexuals in the developing world, but it is infecting increasing numbers in developed countries as well.
- ◆ HIV/AIDS has enormous social and economic significance: in addition to the deaths directly caused. It is affecting population structures, increasing the spread of some other infectious diseases and placing a strain on health budgets across the world.
- ◆ Infectious diseases are caused by pathogens which are usually bacteria, viruses, protoctists, and fungi. They remain the leading cause of death in many developing countries.
- ◆ Cholera, malaria, HIV and TB cause large numbers of deaths but are difficult to control.
- ◆ Disease prevention involves preventing people from becoming infected. Disease control involves managing people who do have the disease to prevent its spread.
- ◆ Social, economic and biological factors all have a role in prevention and control.

consider insignificant today, such as endocarditis (rheumatic fever) and the infections of wounds caused rapid death before antibiotics were discovered.

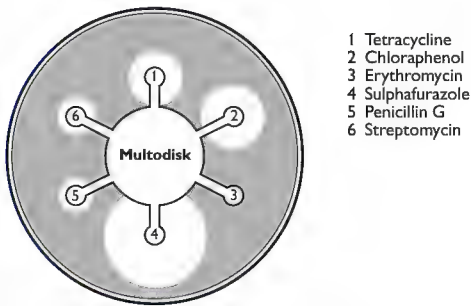
Antibiotics work by interfering with one or more of the essential functions of bacterial cells. They do not harm human cells due to the differences in cell structure between bacterial (prokaryotic) and animal (eukaryotic) cells. Antibiotics are usually specific to certain types of bacteria, and thus it is common practice to find out which bacterium is responsible for an infection before attempting to treat it. **Broad spectrum antibiotics** will work on all or most types of bacteria, but can be harmful as they also kill useful bacteria in the gut.

Antibiotics use one or more of the four main targets outlined below to attack bacterial cells:

- ▼ Interfering with production of the bacterial cell wall, particularly by inhibiting the formation of peptide cross-links within the wall, leading to cell breakdown (lysis) by osmosis as the delicate cell surface membrane cannot resist over expansion by the entry of water, without the surrounding cell wall.
- ▼ Damaging bacterial cell membranes.
- ▼ Limiting or preventing protein synthesis, especially the synthesis of enzymes.
- ▼ Limiting or preventing nucleic acid synthesis and hence cell division.

Antibiotic resistance has arisen over the past fifty years as a result of the excessive use of antibiotics. Such resistant bacteria acquire the ability to destroy the antibiotic, be impermeable to it, or have

Diagram to show action of specific antibiotics on a bacterial culture



sites normally targeted by antibiotics altered so that the antibiotic cannot interfere with cellular activities. All the antibiotics are therefore less effective, and some completely ineffective at killing the bacteria. Resistance may come in two main ways: through genetic mutations in bacterial DNA, or through introduction of resistance genes via other bacteria or viruses. The very short generation time and massive (asexual) reproductive potential of bacteria allows any beneficial mutations to be passed on very rapidly. (Some bacteria can divide to produce two new bacteria about once every 30 minutes, so that a single bacterium could theoretically result in a population of  $2^{47}$  by the end of a 24 hour period.)



Two important examples of resistant bacteria (sometimes referred to as 'superbugs') are Multiple Resistant *Staphylococcus aureus* (MRSA) which is a common cause of infection in hospitals, and some strains of *Mycobacterium tuberculosis* which causes TB. Whilst random mutations of bacterial DNA which confer antibiotic resistance can occur at any time, the problem is made worse if courses of antibiotics are not completed or if sub-optimal doses are taken. A bacterium may, for example, require two specific mutations to make it fully resistant to an antibiotic. If one mutation offering partial resistance is acquired mid-way through a course of antibiotics the remaining days of treatment may eventually kill this bacterium even though they may do so more slowly than before. However, if the antibiotics are stopped, the bacterium with one mutation for partial resistance may acquire a second mutation. Together with the first this may offer total resistance. When 'multi-drug' treatments (many different types of antibiotic together) are used the chance of a bacterium developing resistance to all types at once is very low. But it is still possible because bacteria may pass genetic material from one to another. This is again more significant if courses are not completed and mixed populations of partially resistant bacteria occur together in a patient.

Antibiotic resistance is already responsible for increasing rates of illness and death from *Staphylococcus aureus*, and T.B. Health professionals are worried that the problem will increase if more bacteria become resistant to antibiotics, allowing common infections to once again become major causes of death across the world. They are calling for a reduction in the unnecessary use of antibiotics. This could include a reduction in the number of prescriptions of the drugs for minor infections in humans, and a reduction in the use of antibiotics in farming (60% of total antibiotic use) where they are added to feeds as growth promoters and to prevent disease.

#### ◆ CHECKPOINT SUMMARY

- ◆ Antibiotics are substances produced by microorganisms which can kill or inhibit the growth of other organisms (usually bacteria).
- ◆ Bactericidal antibiotics kill other bacteria: bacteriostatic antibiotics inhibit the growth of other bacteria.
- ◆ Antibiotics are produced on a large scale using fermenters. Microorganisms producing them may be genetically engineered.
- ◆ Antibiotics were discovered in 1928 and have been in use since 1940s. Their use has caused an enormous reduction in severe illness and death from bacterial infections.
- ◆ Antibiotics interfere with essential functions of bacterial cells. They may upset synthesis of the bacterial cell wall, or prevent the production of proteins (enzymes) and nucleic acids.
- ◆ Antibiotics may be broad spectrum, killing most types of bacteria or specific to one particular species.
- ◆ Overuse of antibiotics in medicine and in farming industry has led to the emergence of some resistant strains of bacteria.
- ◆ Resistant strains of bacteria are not affected by antibiotics and hence can be very dangerous to humans as the infections they cause are untreatable and spread rapidly.
- ◆ Resistance often arises through random genetic mutations in bacterial DNA.
- ◆ Some strains of TB and *Staphylococcus aureus* are now resistant to all types of antibiotics. They are said to be 'multi-drug resistant'.

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## 2.6.

# Immunity

### Content

- ▼ The immune system
- ▼ The role of vaccination in controlling disease

### Learning Objectives

Candidates should be able to:

- a) describe the origin, maturation and mode of action of phagocytes and lymphocytes.
- b) explain the meaning of the term immune response.
- c) distinguish between the actions of B lymphocytes and T-lymphocytes in fighting infection.
- d) appreciate the role of memory cells in long term immunity.
- e) relate the molecular structure of antibodies to their functions.
- f) distinguish between active and passive, natural and artificial immunity and explain how vaccination can control disease.
- g) discuss the reasons why vaccination has eradicated smallpox but not measles, TB, malaria or cholera.
- h) outline the role of the immune system in allergies, with reference to asthma and hay fever.

### Introduction

Immunology is the name given to the study of the ways in which the immune system allows the body to protect itself from disease-causing organisms (**pathogens**) which have entered the body.

The human body is well adapted to prevent pathogens (mainly bacteria, fungi and viruses) from entering in the first place. There are several ways in which this is achieved:

- ▼ The skin forms a protective barrier against most pathogens. If it is cut, blood clotting helps to seal the wound and prevent pathogen entry.
- ▼ The mucus membranes of nose and respiratory tract filter the air using small hairs called cilia and trap pathogens in the sticky mucus for destruction by phagocytes.
- ▼ Anti-bacterial enzymes in saliva, sweat and tears help to destroy pathogens
- ▼ The stomach acid (pH 2) kills most pathogens which may enter via food or water

If however, these mechanisms fail and pathogens do enter the body tissues or blood, an **immune system** is necessary to attack and destroy these pathogens and so prevent serious disease or death. The immune system uses several specialised types of white blood cells, the most important being the phagocytes and the lymphocytes.

## The ORIGIN, MATURATION and MODE of ACTION of PHAGOCYTES and LYMPHOCYTES

Phagocytes and lymphocytes, like red blood cells and platelets, are made by special cells known as **stem cells** found in the liver, spleen and bone marrow (tissue found in the centre of bones) of the fetus. In children they are found in the marrow of all bones, and in adults in the marrow of bones of the central skeleton, especially the sternum, the hip bone and the top ends of the femur (leg) and humerus (arm) bones.

The nuclei of stem cells are constantly dividing by mitosis to produce **identical** daughter cells. These cells all have the same genes and so have the potential to develop into any type of blood cell. They are said to be 'pluripotent'. Yet by expressing or 'switching on' different sets of these genes the daughter stem cells can differentiate into red blood cells, phagocytes or lymphocytes with their very different functions.

### Phagocytes

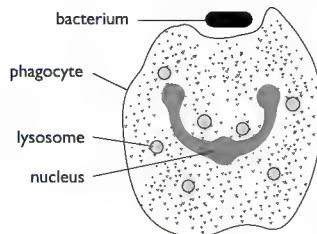
These are white blood cells (leucocytes) that can engulf and digest pathogens, other foreign material and dead or infected cells. They are **non-specific** in their actions so will deal with any type of foreign material which they come across. They have a distinctive appearance with a lobed nucleus and grainy cytoplasm. Phagocytes are mainly found in the blood and the lymphatic system, especially in the lymph nodes. They are also capable of squeezing through the tiny gaps between cells in the walls of capillaries and entering the tissue fluid which surrounds every cell. This is important as it allows the phagocytes to act in any body tissue which becomes infected with pathogens. Phagocytes are also found in the alveoli of the lungs where they attack pathogens entering via the air.

### Lymphocytes

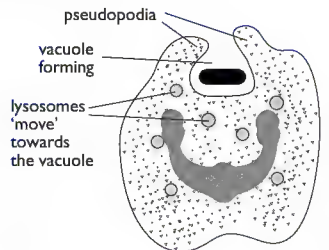
These are white blood cells that are involved in very **specific** immune responses against pathogens. They do not engulf and digest pathogens, but use other, more complicated processes to destroy them. Like phagocytes, lymphocytes circulate in the blood and lymph fluid and are also found within the lymph nodes. They have a large rounded nucleus which almost fills the cell and a small amount of non-grainy cytoplasm.

Having developed in the bone marrow, lymphocytes move through the body to the spleen and lymph nodes where they mature and become active. Some of these lymphocytes move directly to the spleen and lymph nodes and are known as **B-lymphocytes** or B-cells. Other lymphocytes move to the spleen and lymph nodes via the thymus (a gland found beneath the sternum at the top of the chest) where they undergo further differentiation. These develop into **T-lymphocytes** or T-cells (T for thymus).

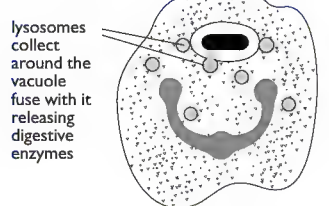
#### Phagocyte 'moves' towards bacterium



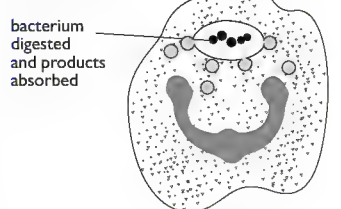
#### Vacuole forming



#### Vacuole formed



#### Lysosomes fuse with vacuole and release enzymes



## Learning Outcome 11

### The IMMUNE RESPONSE

B-lymphocytes and T-lymphocytes both respond to the presence of specific types of foreign material in the body and bring about actions to remove them. Such foreign material includes pathogens as well as 'non-self' human cells (such as the cells of blood or organs transplanted from other people) and substances in certain foods or other materials which bring about allergic reactions. Although B-lymphocytes and T-lymphocytes work in very different ways, the starting point for both is the recognition of an **antigen**. With regard to pathogens, antigens are surface protein molecules which trigger an immune response.

## Learning Outcome 12

### The ACTIONS of B-LYMPHOCYTES and T-LYMPHOCYTES

#### B-lymphocytes

The function of B-lymphocytes is to produce antibodies in response to antigens in a process known as **humoral immunity**. On the cell surface membrane of B-lymphocytes are a number of specific **antigen receptors** or membrane bound antibodies. These are sites to which antigens on the surface of pathogens may become attached, leading to a sequence of events in which free antibodies are produced to prevent the pathogens from causing harm.

There are many thousands of specific types of B-lymphocyte and each is capable of recognising only one specific antigen from a pathogen. For example, there is one type of B-lymphocyte which will attach to the bacterium causing TB, another type which will attach to the bacterium causing cholera and so on. This specificity is due to slight differences in the shape of the antigen surface receptor protein on each type of B-lymphocyte.

#### Sequence of events in humoral immunity:

- ▼ Pathogen enters body. This may be via droplets in air, via a vector, in food or water, or via body fluids such as saliva, blood or semen.
- ▼ Antigens on surface of pathogen come into contact with their specific antigen receptor on a B-lymphocyte.
- ▼ Binding of antigen to antigen receptor activates the B-lymphocyte and causes it to divide producing a clone of identical B-lymphocytes.
- ▼ Most of the B-lymphocytes turn into **plasma cells** and the rest turn into **memory cells**.
- ▼ The plasma cells begin to secrete specific antibodies against the pathogen concerned. Antibody molecules are secreted at a very high rate: up to 30 000 molecules per second.
- ▼ The antibodies attach to the antigens on the pathogen and lead, indirectly, to the destruction of the pathogen. (See later for details).

#### ◆ CHECKPOINT SUMMARY

- ◆ The body protects itself from becoming infected but has an immune system to attack and destroy any pathogens which do enter.
- ◆ Immunity is associated with white blood cells, particularly the phagocytes and lymphocytes.
- ◆ Phagocytes and lymphocytes are derived from stem cells.
- ◆ Stem cells are found in the liver, spleen and bone marrow.
- ◆ Stem cells are pluripotent: they can divide to form any of the different blood cell populations.
- ◆ Phagocytes are characterised by a lobed nucleus and grainy cytoplasm.
- ◆ Phagocytes engulf and digest pathogens in a non-specific fashion.
- ◆ Phagocytes are found in blood as well as other tissues.
- ◆ Lymphocytes are characterised by a large dense nucleus and non-grainy cytoplasm.
- ◆ There are B and T lymphocytes, both of which are involved in specific immune responses.
- ◆ After maturing in bone marrow, lymphocytes migrate to the lymph nodes.
- ◆ B-lymphocytes migrate directly, T-lymphocytes move via the thymus gland.
- ◆ Lymphocytes are found in blood and lymphatic system, especially in lymph node.

#### ◆ CHECKPOINT SUMMARY

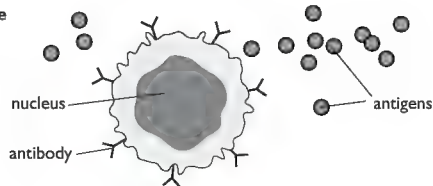
- ◆ B and T lymphocytes recognise foreign material in the body.
- ◆ Foreign material is detected by the presence of foreign surface antigens.
- ◆ Antigens are usually protein molecules found on the surface of all cells which may be pathogens or other human cells. Viruses and non-living material may also possess antigens.
- ◆ An immune response occurs when lymphocytes detect the presence of foreign antigens and set in motion mechanisms to destroy the foreign material.
- ◆ The immune system is important in protecting the body from the damaging effects of pathogens and other foreign materials.

- ▼ Once the pathogens have been destroyed, the plasma cells eventually die and secretion of antibodies stops. But the memory cells remain in the lymph nodes and the circulation in case of a further infection with the same pathogen.

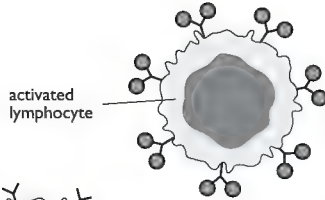
N.B. The above gives the sequence of events in response to a pathogen. It would be similar for any other foreign cell or foreign antigen.

## Humoral Immunity

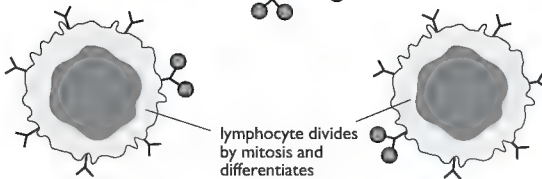
### Immature B lymphocyte



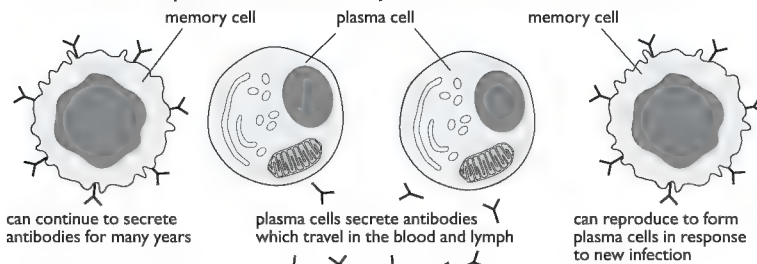
### Activation



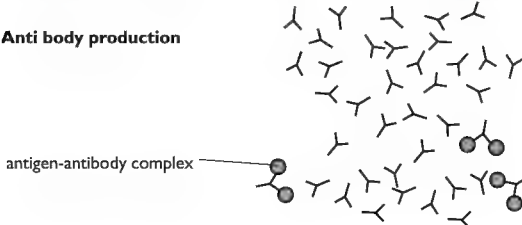
### Division



### Differentiation into plasma cells and memory cells



### Anti body production



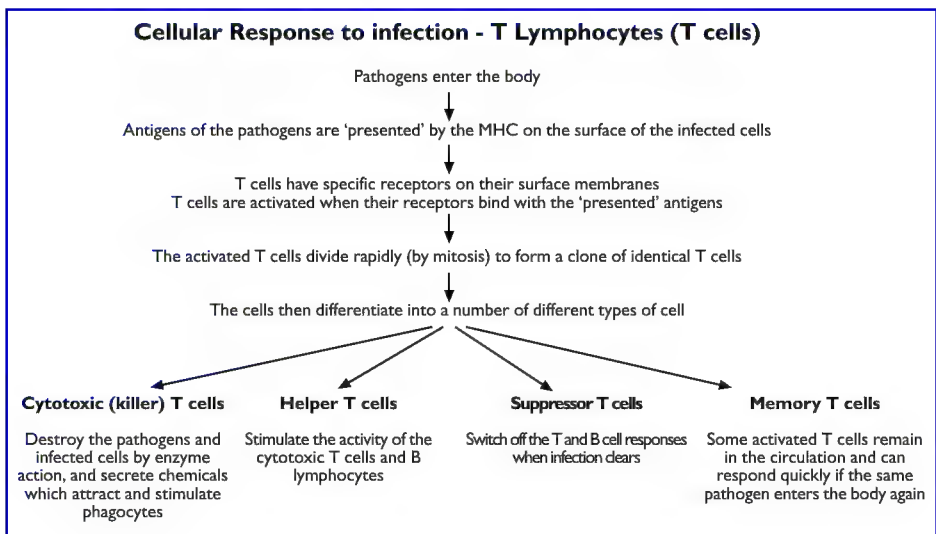
## T-lymphocytes

T-lymphocytes are involved in a different form of immunity known as **cell mediated immunity**. They do not produce antibodies but work directly on infected cells. As with B-lymphocytes, there are thousands of different types of T-lymphocyte each of which only recognise one specific antigen.

T-lymphocytes, like B-lymphocytes, have antigen receptors on their surface. However, unlike B-lymphocytes they cannot recognise antigens from pathogens on their own. They can only recognise them when they have been **processed** by human cells and **presented** on the surface of these cells. This procedure relies on a group of special proteins called the **Major Histocompatibility Complex** (MHC) which are present on the surface of all human cells.

Normally the MHC allows the body's immune system to recognise its own cells and prevent their destruction. However, if a human cell becomes infected with a pathogen, then antigens from this pathogen interact with the MHC molecules and attach to them. They are now 'presented' on the surface of the cell. This alerts the body's immune system to the presence of the pathogen and allows T-lymphocytes to destroy the cell. The cell is known as an **antigen presenting cell**.

Antigens may also be presented by MHC molecules on the surface of B-lymphocytes and phagocytes which are also known as antigen presenting cells. This is important as it allows the different parts of the immune system to **cooperate** with each other. Thus at the same time as producing antibodies, a B-lymphocyte can be presenting an antigen on its MHC and activating T-lymphocytes.



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### Sequence of events in cell mediated immunity:

- ▼ Pathogen enters body.
- ▼ Antigens of pathogen which are presented by the MHC on a body cell come into contact with specific T-lymphocyte receptors which recognise them
- ▼ T-lymphocyte binds to presented antigen on infected cell via antigen receptor
- ▼ T-lymphocyte is activated and divides to form a clone of identical T-lymphocytes which enter the circulation and can attach to other infected cells
- ▼ T-lymphocytes destroy the pathogens inside the cells to which they are bound. Some do this by releasing lytic enzymes into the infected human cells. Others release chemical messengers called cytokines which attract phagocytes to engulf the cells
- ▼ Some T-lymphocytes then turn into memory cells which remain in circulation and in the lymph nodes in case of further infection.

### Helper and Suppressor T-lymphocytes

The T-lymphocytes described above are called **cytotoxic T-lymphocytes**. There are also two other types of T-lymphocyte which work in different ways. **Helper T-lymphocytes** 'help' B-lymphocytes and cytotoxic T-lymphocytes to function by releasing chemicals called cytokines and interleukins which stimulate the activity of the lymphocytes. They are only able to do this once they have been activated by binding to an antigen presented on an antigen presenting cell (It is these T-lymphocytes which are destroyed by the HIV virus, resulting in a depression of immunity). **Suppressor T-lymphocytes** are important in switching off the B- and T-lymphocyte responses to a particular pathogen once the infection has been cleared.

#### ◆ CHECKPOINT SUMMARY

- ◆ The type of immune response associated with B-lymphocytes is termed humoral immunity and involves the production of antibodies.
- ◆ There are thousands of different types of B-lymphocyte, and each type will only recognise one specific type of antigen.
- ◆ B-lymphocytes have antigen receptors which detect and bind to foreign antigens.
- ◆ Binding of antigen to antibody activates the B-lymphocyte, causing it to divide.
- ◆ B-lymphocytes in the clone divide into either plasma cells or memory cells
- ◆ Plasma cells secrete specific antibodies against the pathogen
- ◆ Memory cells remain in the body in case of future infection with the same pathogen.
- ◆ T-lymphocytes are associated with cell mediated immunity: the direct killing of infected cells.
- ◆ As with B-lymphocytes, there are many types of T-lymphocytes, each being specific to one antigen.
- ◆ T-lymphocytes can only recognise foreign antigens when presented on the surface of a human cell by an MHC molecule. Recognition involves specific antigen receptors.
- ◆ When a T-lymphocyte is activated by binding to its specific antigen it will proliferate to form a clone of identical cells.
- ◆ T-lymphocytes may destroy infected cells by releasing lytic enzymes.
- ◆ There is co-operation between T-lymphocytes and other components of the immune system including helper and suppressor T lymphocytes, phagocytes and B-lymphocytes.

## MEMORY CELLS and LONG TERM IMMUNITY

Both B-lymphocytes and T-lymphocytes form memory cells after encountering a pathogen in the body. The function of these is to allow the body to 'remember' pathogens it has encountered before and produce a much faster immune response to them the second time around.

When a familiar antigen is encountered, T-lymphocyte memory cells will divide to form functional T-lymphocytes, which enter the circulation and move to the area of infection. They are known to move preferentially to the area of the body where they encountered that specific infection before.

Similarly, B-lymphocyte memory cells will divide and form new antibody producing plasma cells when they encounter their familiar pathogen. In each case, some memory cells will always be left so that the body can respond to any number of future infections with the same pathogen.

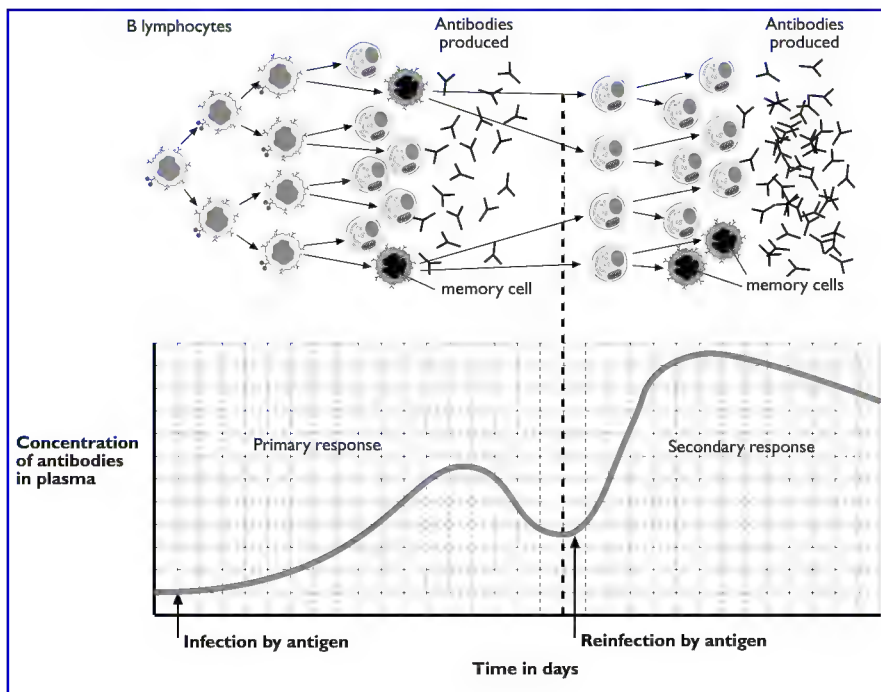
Two main differences exist between the first or **primary response** by B-lymphocytes to a pathogen, and the **secondary response**.

Antibodies are produced more rapidly in the secondary response.

Larger amounts of antibodies are produced in the secondary response.

### ◆ CHECKPOINT SUMMARY

- ◆ Both B and T-lymphocytes form memory cells during a first encounter with an unfamiliar pathogen. These remain in the body in case of future encounters with the same pathogen.
- ◆ Memory cells are activated if the pathogen is encountered again.
- ◆ T-lymphocyte memory cells divide to form new functional T-lymphocytes.
- ◆ B-lymphocyte memory cells form new plasma cells which secrete antibodies.
- ◆ The secondary antibody response is more rapid and larger than the primary response.
- ◆ Memory cells can provide life-long immunity to some pathogens but not to others.
- ◆ The production of memory cells can be stimulated naturally or artificially via vaccination.





The presence of memory cells means that with some diseases such as mumps or chicken pox one infection can make a person **immune** to that infection for the rest of their life. The pathogens causing these diseases will almost certainly get into their body again during that time, but the immune response is so rapid that they will not become ill. With other infections, such as malaria, and influenza, people can suffer many bouts of illness from the same type of pathogen. This is because such pathogens have a very high mutation rate in the genes coding for antigen proteins. The structure of the antigens changes slightly and the memory cells fail to recognise it.

## Learning Outcome (LO)

### The STRUCTURE and FUNCTION of ANTIBODIES

Antibodies are molecules released by B-lymphocytes in response to specific antigens. They are found in the blood plasma and are a type of protein molecule known as **immunoglobulins**.

Each antibody consists of four polypeptide chains which are folded to form a molecule shaped like a Y. The straight tail of the Y is known as the **constant region** and is the same in every type of antibody. The forked part of the Y is known as the **variable region** as this is the part which varies slightly in shape between each type of antibody.

Differences in the amino acid sequence of the polypeptide chains which make up the variable region create antigen binding sites of different shapes. Each antibody thus has the ability to bind only to antigens of corresponding shape to itself. (Antibodies may be thought of as keys which will only fit into the locks of specific antigens). For example, an antibody with the specific shape to bind to the TB causing bacterium will not bind to antigens on the bacterium which causes cholera.

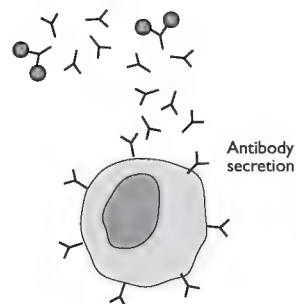
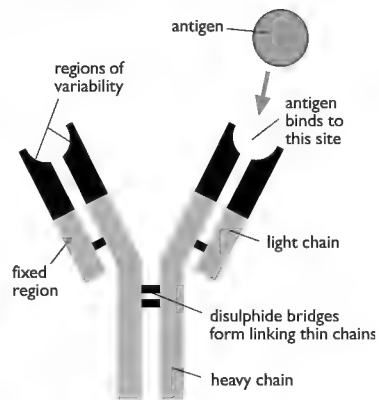
There are three main ways in which antibodies help to destroy pathogens:

- ▼ By coating pathogens and causing them to stick together in such a way that they can then be engulfed by phagocytes.
- ▼ By binding to pathogens at sites which interfere with their activities. For example, by covering the protein coat of a virus and preventing it from attaching to host cells.
- ▼ By stimulating other blood components called **complement** to destroy the pathogen.

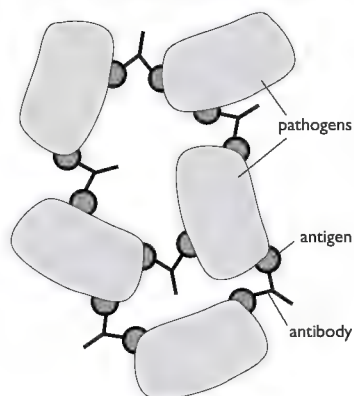
#### ◆ CHECKPOINT SUMMARY

- ◆ Antibodies are produced by plasma cells when in response to specific antigens.
- ◆ Antibodies are a type of globular protein molecule called immunoglobulins which are made up of 4 polypeptide chains.
- ◆ Antibodies are shaped like a Y. The tail of the Y is the constant region and is always identical.
- ◆ The fork of the Y is the variable region and contains the antigen binding site: it varies between antibodies giving them specificity to certain antigens.
- ◆ Antibodies do not directly destroy pathogens but achieve this in interaction with other components of the immune system.

#### Structure of an antibody



#### Pathogens trapped ready for phagocytosis



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## TYPES OF IMMUNITY

### Active immunity

The type of immunity to a disease which follows a natural infection with a pathogen is known as **natural active immunity**. As described above it involves a pathogen entering the body and stimulating the production of memory cells for future protection against the same disease. The person does not necessarily have to get ill from the infection for the immune system to work in this way.

### Vaccination

This works in a similar way to natural active immunity. A person is given a very small dose of the pathogen or a 'toxin' produced by the pathogen to which immunity is required. Usually this is in the form of an injection, but oral vaccines also exist for some diseases. This type of immunity is known as **artificial active immunity**, since the pathogen is introduced to the body in an artificial manner and the person does not usually get ill from the disease as they often do in natural active immunity. Following vaccination, B-lymphocytes are stimulated to produce plasma cells and hence antibodies, and memory cells. T-lymphocytes may also be stimulated and produce memory cells. These memory cells remain in the body and allow the person to respond quickly if they encounter the same pathogen again, preventing them from becoming ill.

If a vaccine contains the pathogen itself, the pathogen may be dead or living. If living, there is a risk of causing illness from the vaccination, thus the pathogen used is often a naturally occurring mild strain, or it has been attenuated (weakened) in some way to reduce its virulence, its growth rate, or both. Recently this has been achieved by genetically engineering pathogens. In rare cases, a closely related pathogen to the one for which immunity is sought, has such similar antigens that it may be used instead. This was the case with the early smallpox vaccines which were made from the cowpox virus. Some very new genetically engineered vaccines, including the hepatitis B vaccine do not use a pathogen at all: instead genes controlling the production of antigens are transferred from the virus to cells of a micro-organism (such as yeast) where the antigen can be produced safely in culture.

Some vaccines provide complete immunity after a single dose. Others require a second dose known as a 'booster' to allow a greater number of memory cells to form.

Vaccination is a very safe way of gaining immunity to diseases which might otherwise cause serious illness or death if caught naturally. It has had an enormous impact in reducing death and debilitation from infectious disease in childhood. In countries where there seems to be little threat of diseases like measles some parents may be reluctant to have their child vaccinated. Whilst there may be reasons for this, such practice undermines the effectiveness of vaccine programmes. However, in the developing world vaccination can carry the serious threat of infection with HIV/AIDS via the reuse of needles.

Passive immunity

This is the process whereby ready made antibodies are given to a person to offer them rapid but short-term immunity to a disease. It is called passive because the person plays no role in actually producing the antibodies against that disease. Since memory cells are not given nor their production stimulated, such passive immunity will only last a few weeks or months, after which time the antibodies will be broken down by the body and stop working. There are two types of passive immunity.

Natural passive immunity

This occurs when antibodies are passed from mother to fetus via the placenta, or from mother to baby via the colostrum (first milk). These antibodies protect the baby from diseases which it may encounter in the first few months of life before its own immune system starts functioning properly.

Artificial passive immunity

This occurs when antibodies produced in another organism are injected into a person to give them short term protection against a specific disease. Antibodies may be given to a person who has already got the disease (such as someone who has got rabies from a bite by an infected dog) or to a person who is at risk of a catching a disease such as tetanus. In the past, such antibodies could only be obtained from the blood of other animals (who had been infected with the pathogen) in the form of 'anti-serum' (serum being the blood plasma without its large proteins).

Now some of the antibodies required for passive immunisation are produced as **monoclonal antibodies** in the laboratory. These are antibodies produced by a single clone of identical B-lymphocytes (plasma cells). They are produced by cells known as **hybridomas** which are created in the laboratory by fusing a plasma cell of the desired type (one that produces antibodies against a specific pathogen) with a cancer cell (myeloma). The hybridomas have the dual ability to constantly divide, like a cancer cell, and to produce antibodies like a plasma cell. The monoclonal antibodies produced have a variety of uses in medicine, research and diagnostic tests.

The use of vaccination in controlling disease.

The principle of vaccination was first demonstrated scientifically by Edward Jenner in 1796. Jenner infected a young boy with cowpox (by scratching the boy's skin and inserting some pus from a cowpox pustule) and made him immune to the related but deadly disease, smallpox. In performing this potentially hazardous experiment, Jenner was exploiting local knowledge regarding the immunity of milk maids to small pox owing to their regular contact with the cowpox virus. His work had an enormous impact, since at that time smallpox was a major killer and about a quarter of people who caught the disease died.

Since Jenner's time, and especially in the past one hundred years when the pathogens causing most infectious diseases have been identified, many different vaccines have been produced. Such vaccines have played a major role in reducing the number of deaths

from infectious diseases such as, polio, measles, and TB, although only in the case of smallpox has a vaccination programme led to the complete eradication of a disease.

In Britain today, most young children are vaccinated against a variety of diseases including measles, mumps and *Rubella* (MMR), diphtheria, tetanus and whooping cough (DTP) and polio. Later on they receive vaccines against TB, and possibly other diseases such as hepatitis, yellow fever, typhoid and cholera if travelling abroad.

Whilst vaccination is important in protecting individuals against disease, it is more significant in terms of controlling the disease in the whole population of a country or region. In 'controlling' a disease, a vaccination programme aims to reduce the number of cases of illness and death from the disease to a low level, to ensure that there are few infectious carriers of the disease in the population and few non-immune people who are susceptible to the disease.

Success in disease control, and ultimately in disease eradication, will only be achieved if the vast majority of people in the country (or in the whole world in the case of eradication programmes) cooperate and agree to be vaccinated. In order for this to occur, the government of the country must actively promote vaccination, or even make it compulsory. Vaccination should be free and easily available to all people in the population. In addition, the population must be educated about the disease and the vaccine so that they appreciate the importance of the vaccination.

It is, however, very difficult to meet all of these conditions, even if there is money and government support for the vaccination programme. Firstly, the populations of countries and regions are always changing: new people are born, old people die and people migrate into and out of the area, altering the proportion of those with immunity to the disease. Secondly, some people will not agree to vaccination as they believe that the vaccine itself can cause illness or even death. Thirdly, some diseases, for example tetanus, can exist in other animals (animal reservoirs) and/or in the soil. This means that even if everybody is vaccinated it is very unlikely that the disease could ever be eradicated.

## Learning Outcomes (LO)

### The EFFECTIVENESS of VACCINATION in ERADICATING and CONTROLLING DISEASE

#### Smallpox

This is caused by the *Variola* virus, and was declared officially eradicated (absent from all human populations and from anywhere else in the environment) in 1979, so people are no longer vaccinated against this disease. This is the only example of a disease being eradicated by human intervention. The eradication programme required a huge amount of funding as well as close international cooperation. There were several features of the disease which helped to make the eradication effort successful:

- ▼ Smallpox was a very recognisable disease. People were familiar with the symptoms.
- ▼ Smallpox had no long term carriers (people who showed no

#### ◆ CHECKPOINT SUMMARY

- ◆ Natural active immunity, involving memory cells, results from a natural infection with a pathogen.
- ◆ Artificial active immunity, which also involves memory cells, is provided by vaccination.
- ◆ Vaccination is the process whereby a small quantity of material from a pathogen is deliberately introduced into the body in order to stimulate lymphocytes to make an immune response.
- ◆ Vaccines may contain dead pathogens, live attenuated pathogens, or toxins or antigens from pathogens.
- ◆ Genetic engineering is used in the production of some vaccines.
- ◆ Vaccines generally provide a safe and effective way of gaining immunity to a disease.
- ◆ Passive immunity involves the provision of ready made antibodies to a person.
- ◆ Passive immunity does not stimulate lymphocytes or memory cells. It is short term.
- ◆ Natural passive immunity is provided for a fetus when antibodies cross the placenta, or for a baby via antibodies in colostrum.
- ◆ Artificial passive immunity involves a person being injected with antibodies against a disease he/she has or is at risk of in the short term.
- ◆ The principle of vaccination was first scientifically demonstrated by Jenner in 1796.
- ◆ Since Jenner, vaccination has had a dramatic impact on deaths from a range of infectious diseases, especially in childhood.
- ◆ A vaccination will prevent an individual getting ill or dying from an infectious disease but it can also control the disease within the community or region if people cooperate.

symptoms of illness but were still infectious, as may happen with TB, malaria and cholera).

- ▼ The smallpox virus could only be spread directly from one person to another. It could not survive in any other animal, in the water or the soil. This limited its rate of survival and spread.
- ▼ The smallpox vaccine was very effective and provided total life long immunity (as did natural infection in those who survived). Vaccination created a distinctive scar on the arm, marking those already vaccinated. No 'booster' vaccines were needed.
- ▼ The smallpox virus was very stable. Unlike the HIV virus and the prototist malaria parasite, its genes did not mutate and change its surface antigens.

The success of vaccinations against other diseases has been mixed. The measles and TB (BCG) vaccines have been very successful in reducing illness and death, while the cholera vaccine has been used in only a limited way. There is still no effective malaria vaccine. Reasons for such variations in the effectiveness of vaccination programmes relate to the types of pathogens involved, their means of transmission, the nature of the diseases caused and financial and political considerations.

**Measles**

A measles vaccine has been around for almost fifty years and saves millions of lives per year, yet the disease still occurs all over the world and kills many children in the developing world. Reasons for this include:

- ▼ Measles is one of the most highly infectious diseases being passed by droplet infection from one person to another very rapidly
- ▼ To eliminate the disease over 95% of children in towns must be vaccinated. But the rate is usually lower as some parents believe that there is a risk of illness or death from the vaccine
- ▼ In the developed world the disease rarely causes death, so people regard vaccination as less important than for other diseases.

**Tuberculosis (TB)**

TB vaccine (the BCG vaccine) only appeared in the 1930s after the number of deaths and illnesses from TB had already declined dramatically following improvements in living and working conditions. Since 1950 it had been used extensively and has been an important tool in TB prevention and control, yet eradication of TB is unlikely for the following reasons.

- ▼ People without symptoms of TB may be carriers and can transmit the disease (via droplets) for many years, making it harder to trace the spread of infection
- ▼ TB is not very recognisable, and people in the developed world have stopped thinking of it as an important disease. For example, vaccination in some parts of the UK stopped for a few years in the early 1990s
- ▼ The TB vaccination is not 100% effective
- ▼ A form of TB, *Mycobacterium bovis*, exists in cattle and can be transmitted to humans via unpasteurised milk.

## Malaria

Malaria has defied attempts to develop an effective vaccine despite decades of research. The main reasons for this are:

- ▼ DNA of the malaria parasite, has a very high mutation rate and its antigens (encoded by genes) are always changing. The antibodies and memory cells produced by a vaccination may not be effective against new malaria infections where antigens have changed
- ▼ Malaria parasites live in the liver cells and red blood cells of humans. Inside the red blood cells, where they spend the majority of their life cycle they cannot be targeted by either antibodies or T-lymphocytes
- ▼ Humans without disease symptoms often have huge numbers of the parasites in their blood and can thus act as carriers who can pass the disease on to others via female mosquitoes
- ▼ The disease is spread from person to person by the female *Anopheles* mosquito vector which can travel over large distances. This vector has proved very difficult to control in most areas.

Even if a vaccine was available, there might also be logistical and financial problems in vaccinating against malaria which is very widespread in the poorest countries of the developing world.

## Cholera

Cholera vaccination has not been very significant in the control of cholera, and eradication of the disease will not occur with the vaccines that are currently available. Cholera is primarily a disease of poverty and responds best to improvements in sanitation, hygiene and living conditions. The importance of vaccination is limited by the following:

- ▼ The bacterium causing cholera (*Vibrio cholerae*) is spread by the faeco-oral route, (via faecal contamination of water or food sources) allowing the infection to spread very rapidly from one person to hundreds or thousands of others
- ▼ Cholera exists in carriers who have no symptoms but still transmit the disease
- ▼ The vaccination that is currently available is not very effective. It uses heat-killed rather than live bacteria and provides only partial protection for a few months. (It is hoped that a new vaccine containing live genetically engineered bacteria will be more effective).

### ◆ CHECKPOINT SUMMARY

- ◆ Only one disease has been eradicated by vaccination: smallpox, declared eradicated in 1979.
- ◆ Biological reasons for smallpox eradication include the fact that the disease was recognisable, the virus was very stable, had no non-human reservoirs or long term carriers. The vaccine was very effective, provided life-long immunity, and created a distinctive scar.
- ◆ Economic/political factors included a highly coordinated international eradication programme.
- ◆ The success of smallpox eradication has not been repeated for other diseases. Reasons for this are social and economic as well as biological.
- ◆ Measles is highly contagious with a short incubation period. Eradication would require over 95% of people to be vaccinated in all regions. This is highly unlikely in the developed world as the disease is not always considered serious and parents opt out of vaccination.
- ◆ So far it has not been possible to produce an effective malaria vaccine. One reason for this is that the malaria parasite constantly changes its surface antigens, preventing memory cells from functioning effectively. It is also a vector borne disease occurring in poor countries.
- ◆ Cholera is a highly contagious disease with symptomless carriers and non-human reservoirs. It is a disease of poverty and would be most effectively controlled by improved sanitation. The current cholera vaccine, using a dead bacterium does not provide complete immunity.
- ◆ Tuberculosis has both symptomless human carriers and a non-human (bovine) reservoir. It is not always recognisable in early stages, and had ceased to be considered important in the developed world until a few years ago. The vaccine is not 100% effective

## The ROLE of the IMMUNE SYSTEM in ALLERGIES: with REFERENCE to ASTHMA and HAY FEVER

In addition to their specific B- and T-lymphocyte responses to pathogens, humans are also capable of inflammatory responses to unusual antigens in their environment which are not associated with pathogens, such as the toxins in bee stings or insect bites. If, for example, a person is stung by a bee, the toxins stimulate the production of a chemical called **histamine** from mast cells in the skin and connective tissue around the site of the sting. The area becomes warm and swollen with fluid since histamine increases the

flow of blood to the region and makes the walls of capillaries more permeable, allowing tissue fluid containing white blood cells to leak out. This not only brings phagocytes to the site, but also helps to dilute any toxins present.

This normal, protective response to unusual antigens is an important part of the body's immune system. In some individuals, however, the immune system responds **vigorously** and **inappropriately** to antigens on the surface of common materials, leading to severe inflammatory reactions and even death. This is the basis of **allergies**. The substances which cause allergies or allergic reactions are known as **allergens**. These may be living things, such as pollen, or non-living things without protein based antigens such as food additives or some metals. It is not known why some people react to these allergens and others do not, but genetic factors are likely to play a role.

In all types of allergies, antigens on the surface of certain allergens, such as pollen, peanuts or cat fur, stimulate the production of allergen-specific antibodies known as **IgE antibodies**. These in turn bind to and stimulate **mast cells** to produce **histamine**, often in many parts of the body at once.

## Hay fever

This is a very common allergy which is more common in the summer. Antigens on pollen grains from wind pollinated flowers are detected by mast cells, especially those in the nose and eyes. The histamine produced causes the eyes and the lining of the nose to become itchy and to swell up, often leading to sneezing. Excess fluid is released from the tissues causing a 'runny nose' and watering eyes. In some people the pollen antigens also cause the skin to become itchy and swollen and trigger reactions in the lungs leading to asthma.

In most cases of hay fever, common drugs known as '**anti-histamines**' will rapidly reverse the effects of the histamine and reduce the swellings and irritation.

## Asthma

This can be defined as difficulty in breathing caused by constriction (narrowing or closure) of the bronchioles in the lungs. This makes it difficult for air to enter and leave the lungs and sufferers feel 'short of breath'. There are several causes, but one of the most common is an allergic reaction to a specific antigen. Antigens on pollen grains, on dog or cat hair, and on certain foods such as eggs or peanuts may stimulate mast cells in the respiratory tract (trachea and bronchioles) to release histamine. The histamine has three main effects, all of which result in a reduction of the diameter of the bronchioles within the lungs and a consequent reduction in the flow of air into and out of the lungs:

- ▼ the lining of the bronchioles swells up
- ▼ the lining of the bronchioles begins to secrete excess mucus
- ▼ the smooth muscle in the walls of the bronchioles contracts.

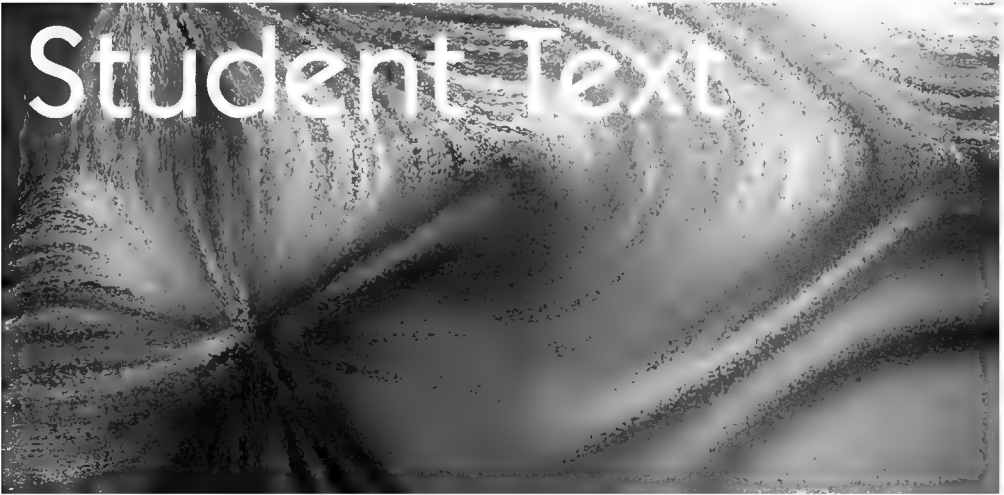
In severe cases of asthma the swollen bronchioles allow such a minimal amount of air to reach the alveoli that death by suffocation can occur. Usually, however, drugs known as 'bronchodilators' taken via inhalers can rapidly reverse the effects of the constricted bronchioles.

### ◆ CHECKPOINT SUMMARY

- ◆ Protective inflammatory responses occur when non-pathogenic antigens (eg. toxins in bee stings) are encountered. This leads to swelling and leakage of tissue fluid in affected areas.
- ◆ In some individuals severe (even life-threatening) inflammatory responses are stimulated by antigens on common materials such as pollen and some foods. This is the basis of allergies.
- ◆ Hay fever is a common allergy caused by antigens on pollen grains. Specific IgE antibodies are produced in response. These bind to mast cells and cause release of histamine.
- ◆ Histamine causes irritation and swelling of the mucous membranes of eyes and nose and release of excess fluid. The skin and lungs may be affected.
- ◆ Hay fever can be treated with anti-histamine drugs.
- ◆ Asthma is a difficulty in breathing caused by constriction of bronchioles.
- ◆ Asthma can result from allergic reactions. Histamine causes the linings of the bronchioles to swell, and secrete excess mucus and causes the smooth muscle in the walls of the bronchioles to contract. All three features reduce air flow into and out of lungs.
- ◆ Drugs to reverse these effects, 'bronchodilators' can be taken via inhalers.

# Biology

Student Text



## 3 Transport

**FELTHAM PRESS**



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# 3: Transport

## Contents

|                                                            |           |
|------------------------------------------------------------|-----------|
| <b>3.1</b><br><b>The Mammalian Transport System</b>        | <b>1</b>  |
| ▼ The need for a transport system in multicellular animals |           |
| ▼ Transport in mammals                                     |           |
| <b>3.2</b><br><b>The Mammalian Heart</b>                   | <b>15</b> |
| ▼ The structure and functioning of the mammalian heart     |           |
| <b>3.3</b><br><b>Transport in Multicellular Plants</b>     | <b>21</b> |

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## 3: Transport

### 3.1

#### The Mammalian Transport System

##### Content

- ▼ The need for a transport system in multicellular animals
- ▼ Transport in mammals

Candidates should be able to:

- a) explain the need for transport systems in multicellular animals in terms of size and surface area to volume ratios.
  - b) describe the structures of arteries, veins and capillaries and be able to recognise these vessels using the light microscope.
  - c) explain the relationship between the structure and function of arteries, veins and capillaries.
  - d) describe the structure of red blood cells, phagocytes and lymphocytes, and explain the differences between blood, tissue fluid and lymph.
  - e) describe gaseous exchange in the alveoli.
  - f) describe the role of haemoglobin in carrying oxygen and carbon dioxide.
  - g) describe and explain the significance of the dissociation curves of adult oxyhaemoglobin at different carbon dioxide levels (the Bohr effect).
  - h) explain the significance of the different affinities of fetal haemoglobin and adult haemoglobin for oxygen.
  - i) describe and explain the significance of the increase in the red blood cell count of humans at high altitude.
-

## The need for TRANSPORT SYSTEMS in MULTICELLULAR ANIMALS in terms of SIZE and SURFACE AREA to VOLUME RATIOS

Unicellular organisms and small multicellular organisms have a large surface area to volume ratio, which means that most cells are close enough to the external medium for diffusion to be sufficient for the exchange of substances. For example the uptake of oxygen and nutrients, and the elimination of carbon dioxide, ammonia and urea. Diffusion is also sufficient for their internal transport. Therefore there is no need for specialised transport systems.

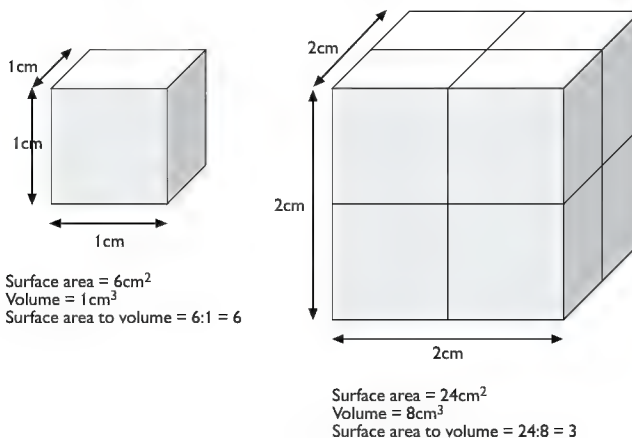
In small multicellular organisms exchanges and internal transport by diffusion are further aided by the particular shapes of some organisms and their parts. For example in the Cnidaria (eg jellyfish, sea anemones, hydra) there is a large body cavity which is filled with the external medium (water); in the Platyhelminthes (the 'flat' worms e.g. the tape worms and liver flukes) there is a flattened body shape. All of these features reduce the distance between the tissues and the external medium to a minimum.

The larger a living organism is, the smaller its surface area to volume ratio is likely to be. With the increase in size and decrease in surface to volume ratio, the development of specialised mass transport systems becomes necessary for the rapid and efficient transport of substances to and from the external medium, and between the different tissues and organs. (It is important to remember that discussions of the development of transport systems also demands consideration of the level of complexity of the organism involved. Some higher animals with transport systems are smaller than some lower animals without.)

In animals with a transport system the blood is circulated around the body by mechanical pumping of a heart and contractile blood vessels. Diffusion is however still important in transport, as it is by diffusion through large surface areas that, substances enter and leave the blood, for example at the lungs and at the surface of the small intestine in mammals, and between the capillary beds and the tissues.

### ◆ CHECKPOINT SUMMARY

- ◆ Surface area increases with size but the surface area to volume ratio (SA/V) decreases.
- ◆ SA/V increased by flattened body shapes and structures.
- ◆ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ◆ Discussions of development of transport systems also involve level of complexity of organism.
- ◆ Development of transport systems involve pumping hearts and tubes.
- ◆ Development of transport systems involve development of specialised exchange surfaces with large surface areas.
- ◆ Diffusion still important in all exchanges, but not in transport throughout volume of organism.



## STRUCTURE and FUNCTION of ARTERIES, VEINS, and CAPILLARIES

In mammals the blood circulates around the body in a continuous system of blood vessels. From the heart, blood travels in the arteries and arterioles, into the capillaries supplying the tissues, and then returns to the heart in the venules and veins.

### Arteries

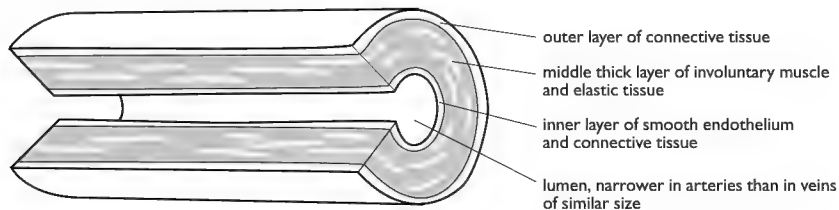
Arteries close to the heart have a large cross sectional area, and thick elastic walls to withstand the high blood pressure. Arteries are stretched by the cardiac output when the heart contracts, and they recoil when the arterial blood pressure drops as a result of the heart relaxing between beats. The recoil of the elastic artery walls in this way assists the circulation of the blood around the body. It helps smooth the flow between contractions of the heart, and helps to maintain the blood pressure. This stretching and recoiling of the arteries is felt as the pulse in places where arteries come close to the surface of the body (the inside of the wrist, the side of the neck, and in the temple).

The main artery leaving the left ventricle of the heart, the aorta, branches into arteries supplying all the main regions of the body. Further from the heart, the arteries branch into smaller arterioles which offer a greater resistance to the flow of the blood so raising the blood pressure. The arterioles penetrate all tissues of the body and connect to beds of finely branching capillaries.

### Capillaries

Capillaries form a fine network which penetrate all tissues. They have the smallest diameter of all blood vessels, about 6-8  $\mu\text{m}$  (0.007 mm), which is the same as that of the red blood cells. For this reason the red cells are forced to move slowly through the capillaries in single file, ensuring a short diffusion distance between the corpuscles and the tissues. Capillary walls are just one cell thick, which further aids exchanges by diffusion between the blood and the tissues. The huge number of capillaries provide a very large total surface area across which these exchanges occur. As more capillaries open up in working muscles, the surface area between the blood and tissues is increased, and the diffusion distance between the two is decreased, resulting in more rapid and efficient exchanges between them. The blood pressure and rate of flow both drop in the

#### Artery in section



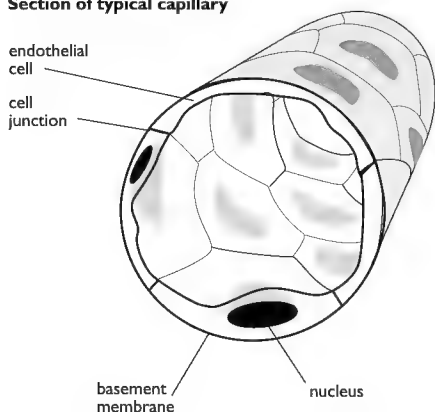
capillaries. The slow flow also increases the time available for exchange of materials between the blood and the tissues.

There are so many capillaries in the body that they cannot all be supplied with blood at the same time. Consequently, there is competition for blood between different regions of the body, especially during exercise, when blood must be shunted to the working muscles, and consequently withdrawn from other regions. For example, when the body is at rest, about 45% of the cardiac output passes through the capillaries of the gut wall and associated glands, and the kidneys. During maximum exercise this can be reduced to about 3% of the cardiac output, as blood is redirected to the working muscles. The reduced flow rate is compensated for by a greater extraction of oxygen from the blood, by these tissues. The shunting of blood between competing tissues is achieved by constriction and dilation of the arterioles, and of the arterio-venous vessels, which are direct connections between the arterioles and venules. The entrances to the capillary beds are controlled by circular precapillary sphincter muscles which, when contracted, shut off the capillaries and when relaxed, open them.

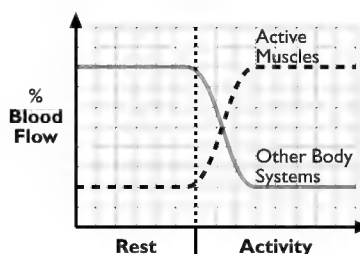
Estimated blood flow in  $\text{cm}^3$  per minute, to different organs/systems in a trained male at rest and during maximum effort.

| Organ system     | At rest | %   | Max. effort | %      |
|------------------|---------|-----|-------------|--------|
| Skeletal muscle  | 1000    | 20  | 26 000      | 88.00  |
| Coronary vessels | 250     | 5   | 1200        | 4.00   |
| Skin             | 500     | 10  | 750         | 2.50   |
| Kidneys          | 1000    | 20  | 300         | 1.00   |
| Liver & gut      | 1250    | 25  | 375         | 1.25   |
| Brain            | 750     | 15  | 750         | 2.50   |
| Whole body       | 5000    | 100 | 30 000      | 100.00 |

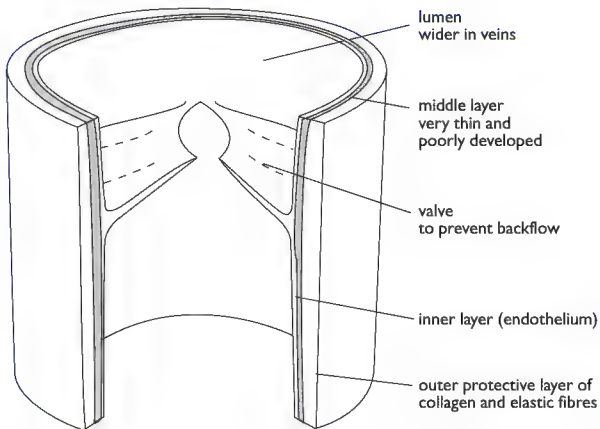
**Section of typical capillary**



**Simplified representation of blood shunting.**



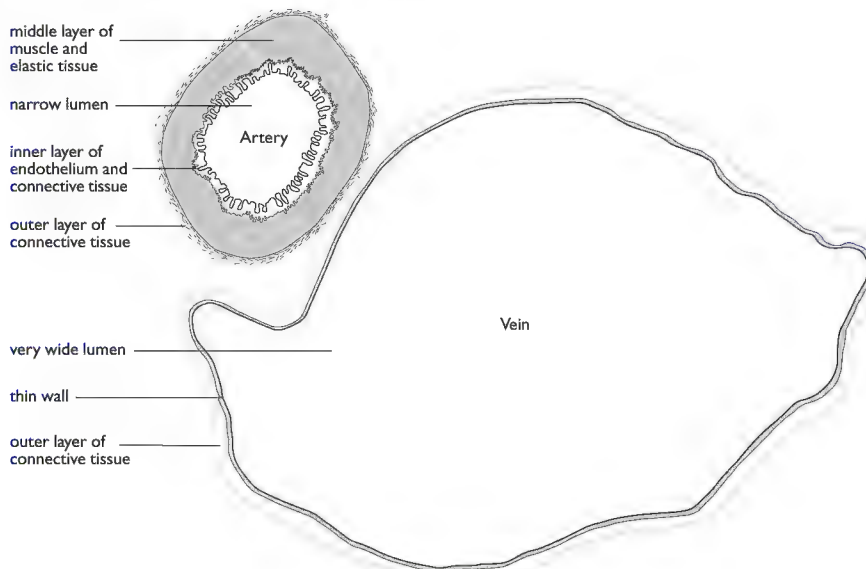
**Section of vein showing pocket valve**



## Veins

Capillaries join up to form **venules**, which in turn join to form veins which return the blood to the heart. The individual veins have a larger cross sectional area than the comparable arteries, and as there are more veins than arteries, the veins also have a greater total cross sectional area. The walls of the veins are thinner and less elastic than those of the arteries, and in the veins of the legs and arms there are semi-lunar or pocket valves at intervals along their length. These valves oppose any back flow of blood under gravity,

**Transverse section of artery and vein as seen under a light microscope**



and ensure one-way flow of blood to the heart. The thin walled veins with their large cross section present little resistance to the flow of the blood. Although the blood pressure in the veins is low after passage of the blood through the capillary beds, the remaining pressure still helps move the blood in the veins back to the heart. Because the blood in the veins is under low pressure, and their walls are thin, the veins are easily compressed by the smallest movements of the surrounding structures, particularly the skeletal muscles. As the muscles contract and relax during exercise they exert a massaging effect on the deep veins, especially for example in the legs, when running, swimming, or cycling. This massage effect of the 'muscle pump' is random and in no particular direction, but the pocket valves in these veins ensure that the flow is one-way, back to the heart.

In addition, breathing movements assist the return of blood in the veins to the heart. On breathing in, the diaphragm contracts and moves downwards. This decreases the pressure within the thorax, and increases the pressure within the abdomen. These changes in pressure compress the large veins in the abdomen, and assist the flow of blood into the veins of the thorax which return blood to the heart.

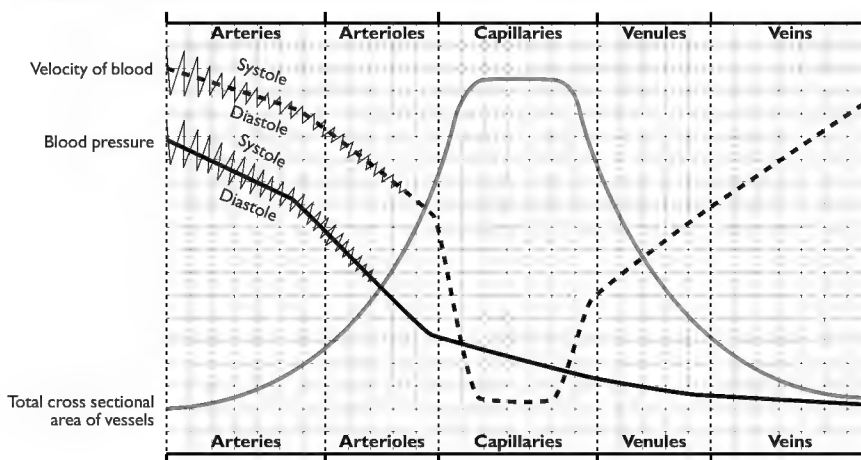
At rest the veins act as a large reservoir of blood for use when circulatory demands increase, for example during exercise. During exercise when the output of blood from the heart (cardiac output) increases, the muscle fibres in the walls of the veins are stimulated to contract (venous tone) and the veins constrict. As a result a larger proportion of the venous blood is shunted back to the heart, especially from the veins in the legs and the abdomen. This is especially important in preventing blood from 'pooling' in the legs under the force of gravity during upright exercise, and immediately afterwards.

In these ways the venous return of blood balances the rising cardiac output during exercise. This is essential as the heart would be unable to maintain a high cardiac output unless it was receiving an equal volume of blood back from the veins.

#### ◆ CHECKPOINT SUMMARY

- ◆ Arteries thick elastic walls with smooth muscle, and lined with smooth endothelium common to all blood vessels.
- ◆ Elasticity of arteries important in smoothing flow of cardiac output resulting in the pulse
- ◆ Arteries divide into smaller branches leading into arterioles
- ◆ Arterioles main site of generation of resistance to blood flow, arterioles lead into capillaries.
- ◆ Capillaries form networks or beds in all tissues particularly rich in active tissues and alveoli of lungs
- ◆ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ◆ Capillaries have large total cross sectional surface area, therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ◆ Diameter of capillary same as red blood corpuscles thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ◆ Capillary walls one cell thick, plasma minus proteins exuded by blood pressure through walls to bathe tissues directly as tissue fluid.
- ◆ Capillaries connect to venules which lead into veins.
- ◆ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ◆ Pocket valves in veins ensure one way flow back to heart.
- ◆ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

**The circulation - velocity, blood pressure and total cross sectional area of vessels**



## The COMPOSITION of BLOOD, TISSUE FLUID and LYMPH

### Blood

Blood consists of the fluid plasma, which carries red blood cells, white cells, and fragments of cells from the red bone marrow known as platelets.

**Plasma** consists of 90% water, and 10% materials in suspension and solution. Plasma proteins, formed mainly in the liver, include albumin (to which the plasma calcium is bound), globulins (of which some are antibodies and some are important in the carriage of hormones and vitamins), and fibrinogen (which is important in blood clotting). These proteins have an important function in buffering the blood (preventing sudden changes in acidity and alkalinity). Plasma proteins are also involved in regulating the movement of water between blood and tissues, which helps to control the volume of tissue fluid. Plasma also contains many dissolved inorganic and organic substances e.g. amino acids, hormones, glucose, fats, urea, creatine, hydrogencarbonate, some oxygen and carbon dioxide. The characteristic yellow straw colour comes from a yellow pigment molecule called bilirubin which is formed from haemoglobin when old red blood cells are broken down in the liver.

**Red blood cells** lose their nucleus and most of their cytoplasmic organelles in their process of maturation. They become 'corpuscles' with a flexible membrane, filled with the oxygen carrying pigment haemoglobin. The loss of the nucleus accounts for their biconcave shape which increases their surface area to volume ratio. The total surface area of the red blood cells in man is about 3500 m<sup>2</sup> and this facilitates the exchange of gases between the red cells and the tissues. The biconcave shape also gives them some resilience in absorbing water without bursting should the plasma become temporarily diluted for any reason. The flexible membrane enables them to 'squeeze' through capillaries.

Red blood cells comprise about 30-40% of the blood volume. This can be determined by centrifuging a blood sample which results in the red blood cells being forced down to the bottom of the sample to give a 'packed red cell volume' or haematocrit. The red blood cell count and haematocrit are proportional to the haemoglobin content of the blood which is quoted in grams per litre (decimetre cubed (dm<sup>3</sup>)), with normal values being within 140 - 180 for men, and 115-160 for women. (Clinically the figures are quoted in grams per decilitre (one tenth of a litre) and are given as 13 - 17g for adult males and 11.5 - 16.0g for adult females.) Levels below the lower limits being known as anaemia.

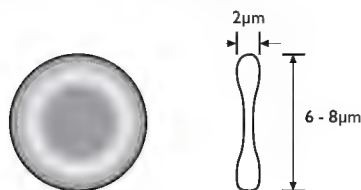
**White cells**, of which there are two main types (phagocytes and lymphocytes), form the basis of the immune system and are described in detail in section 5.2.6. Together with platelets they comprise just 1% of the total blood volume.

**Platelets** are white cell fragments, which have an important function in the clotting process.

### Composition of Blood

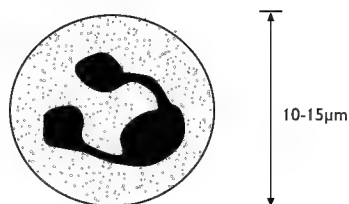
#### Red Blood Corpuscles or Cells

Function: transport of oxygen  
Number: about 5 million per mm<sup>3</sup>



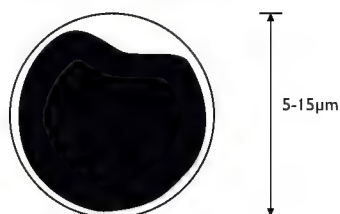
#### Phagocytes eg Neutrophil

Function: engulf foreign bodies  
Number: 3000-6000 per mm<sup>3</sup>



#### Lymphocyte

Function: produce antibodies (B lymphocyte)  
Number: about 200 per mm<sup>3</sup>





## Tissue fluid

Tissue fluid is formed when plasma, minus its proteins, is pushed out under pressure through the capillary walls to bathe the tissues. Depending on the degree of activity and health and fitness, most of the tissue fluid is reabsorbed back into the blood capillaries. Tissue fluid forms the internal environment of multicellular animals. It bathes each cell and is the medium for the exchange of materials between the individual cells and the blood system.

## Lymph

Lymph is that part of the tissue fluid which is not reabsorbed by the blood capillaries, and enters the lymphatic capillaries (which are found in all tissues) of the lymphatic system. The blind-ended lymphatic capillaries lead into wider lymph vessels which are similar in structure to the veins, having thin walls with pocket valves. Contraction of skeletal muscles massages the vessels and the valves ensure unidirectional flow of the lymph back to the major veins near the heart. This in turn aids the draining of tissue fluids.

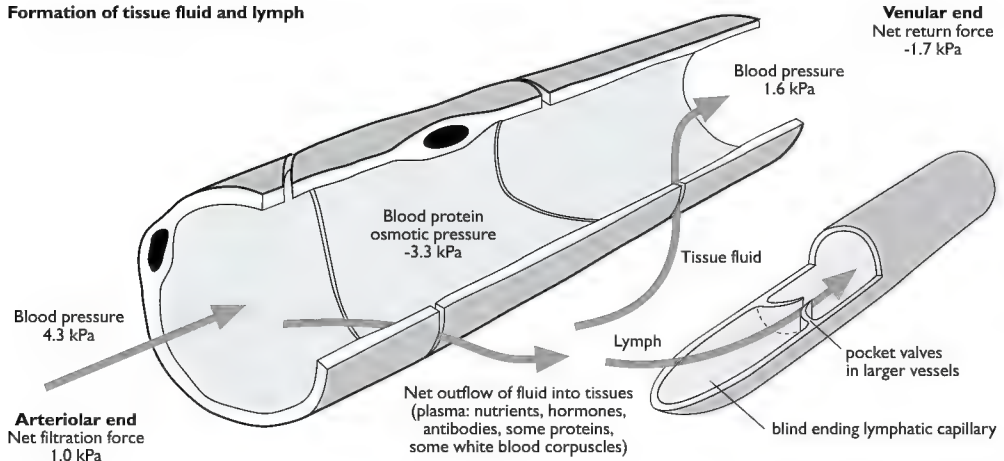
During exercise the blood pressure may increase, more tissue fluid is exuded, the lymph vessels are massaged more vigorously, and therefore the tissue fluid is drained more quickly. All these factors increase the speed of supply of oxygen and nutrients to, and removal of waste products from, the tissues.

At intervals in the lymphatic system are swellings of tissue, called lymph nodes, which contain phagocytes and lymphocytes and play an important role in the defence of the body against infection (see 5.2.6).

### ◆ CHECKPOINT SUMMARY

- ◆ Blood consists of fluid plasma with red blood cells, white blood cells (or white cells) and blood platelets.
- ◆ Plasma 10% materials in suspension and solution.
- ◆ Plasma proteins wide variety of functions and act to buffer changes in pH.
- ◆ Materials carried in solution e.g. glucose, not strictly part of the plasma.
- ◆ Red blood cells lose nucleus in development and become biconcave corpuscles of haemoglobin.
- ◆ Large surface area to volume ratio individually due to biconcave shape, and huge total surface area due to small size (6-8 mm) and huge numbers.
- ◆ Males higher blood count/haemoglobin than females.
- ◆ White cells of which there are several types form basis of immune system (see section 5.2.6)
- ◆ Platelets are fragments of white cells.
- ◆ Tissue fluid basically plasma minus its proteins.
- ◆ Lymph is tissue fluid that has been drained into lymphatic capillaries, with lymphocytes added by lymph nodes which are part of the immune system.

### Formation of tissue fluid and lymph



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## GASEOUS EXCHANGE in the ALVEOLI

Gas exchange occurs by diffusion between the air in the alveoli of the lungs and the blood in the capillaries. The relative amounts of oxygen and carbon dioxide in the air breathed in and out are measured as '**partial pressures**' in units of kiloPascals (kPa). (The continuous random movement of particles of a gas means that the particles will occasionally collide with each other and with the walls of any structure enclosing them within a space, thus exerting a pressure. The number of such collisions, and therefore the pressure, is proportional to the amount of substance present. In mixtures of gases, e.g. air, each substance exerts a partial pressure in that mixture proportional to the amount of that substance in the mixture. The partial pressure of a gas is a better measure of the amount of gas present than its percentage composition. Although the percentage of oxygen remains the same (21%) in air under different conditions, the amount of oxygen varies. At atmospheric pressures less than at sea level e.g. at altitude, there is still 21% oxygen in air, but as the air is less dense there is a smaller amount of oxygen.)

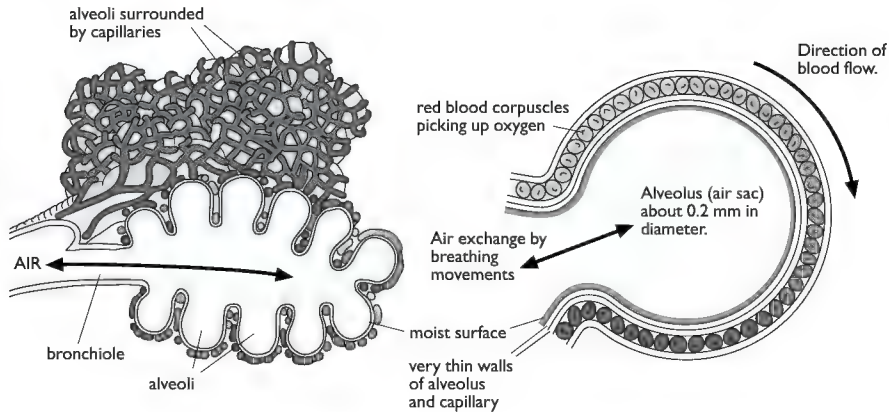
As a result of its journey around the body blood entering the capillaries of the alveoli has a lower oxygen and a higher carbon dioxide content (partial pressure) than the air in the alveoli. Therefore carbon dioxide diffuses out of the blood into the alveoli, and oxygen diffuses into the blood from the alveoli, each down their partial pressure gradients.

The oxygen diffusing into the blood first dissolves in and diffuses through the surface film of moisture on the lining of the alveoli. It then diffuses through the thin walls of the alveoli, through the thin wall of the capillaries, through the plasma, and through the red blood corpuscle membrane. Inside the corpuscle it combines with the haemoglobin to form **oxyhaemoglobin**. At rest about 250 cm<sup>3</sup> of oxygen per minute diffuses into the blood from the alveoli, and this can be increased up to about twenty times during exercise.

Carbon dioxide diffuses in the opposite direction to the oxygen, from the blood plasma into the alveoli. Carbon dioxide molecules are larger than those of oxygen and therefore diffuse more slowly in the gas phase, but carbon dioxide is much more soluble than oxygen and therefore diffuses about twenty times more readily in solution than oxygen across the capillary-alveolar barrier. This explains why sufficient exchange of carbon dioxide still occurs even though the pressure gradient of carbon dioxide is only 6 mm Hg compared to 60 mm Hg for oxygen.

The exchange of gases by diffusion across the alveolar-capillary barrier depends on many factors. Although the most important factor is the difference in partial pressure of gases across the barrier, the surface area and thickness of the barrier are also significant. The alveoli of the lungs have a huge total surface area, and their walls are made up of very thin flat lining cells (squamous epithelium). The capillaries of the pulmonary circulation are sandwiched between the thin walls of adjacent alveoli, causing the alveoli surfaces to be ridged and corrugated, which further increases their surface area. These capillary networks are the most dense in the body. The capillaries also have very thin walls, so that the total thickness of cells between the air and blood is reduced to a minimum.

### Diagram showing structure of an alveolar sac

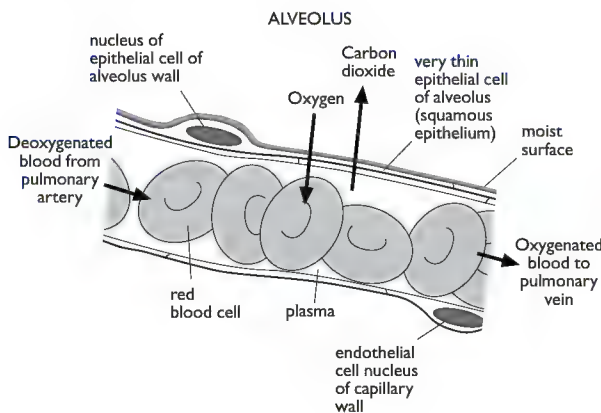


At rest, the speed of circulation of the blood through the lungs is such that the contact time between the blood and the wall of an alveolus is about 0.75 seconds. During exercise, this is reduced to about 0.35 seconds, and oxygen uptake can increase up to 5000 cm<sup>3</sup> per minute. This is a result of the increase in ventilation of the lungs, the increased blood flow through the pulmonary circulation, and increased rates of diffusion.

#### ◆ CHECKPOINT SUMMARY

- ◆ Gas exchange occurs over large surface area of alveoli which is a product of their relatively small size and large number.
- ◆ Diffusion gradients of oxygen and carbon dioxide dependent upon partial pressures of gases on either side of diffusion surface.
- ◆ Diffusion surface composed of thin squamous epithelium ridged around the sandwiched capillaries.
- ◆ Surface water an inevitable consequence of a permeable surface exposed to air decreases diffusion of oxygen more than the diffusion of carbon dioxide.
- ◆ Air in alveoli remains fairly constant in composition independent of breathing cycle.
- ◆ Diffusion gradients maintained by circulating blood.
- ◆ As demand for oxygen increases so does steepness of diffusion gradients and speed of circulation thus meeting extra demand.

#### Gas exchange alveolus/capillary



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## ROLE of HAEMOGLOBIN in CARRYING OXYGEN and CARBON DIOXIDE

Oxygen absorbed into the blood in the alveolar capillaries combines with haemoglobin in the red blood cells to form **oxyhaemoglobin**. Each molecule of mammalian haemoglobin consists of four sub-units, each consisting of an iron-containing haem group combined with a protein globin part. Each subunit combines reversibly with one molecule of oxygen. Thus one molecule of haemoglobin can carry four molecules of oxygen. The formation of oxyhaemoglobin from deoxyhaemoglobin involves a physical holding of the oxygen by the haemoglobin sub-units as a result of their special 3-dimensional structure. In man each red blood cell contains about 300 000 000 molecules of haemoglobin. At rest and even during maximum exercise, at sea level, the haemoglobin in the blood leaving the lungs in healthy subjects is virtually saturated with oxygen. Therefore the capacity and functioning of the lungs is not normally the limiting factor in exercise.

The oxygen is easily displaced by carbon monoxide, which combines irreversibly with haemoglobin to form carboxyhaemoglobin. Major sources of carbon monoxide being smoking and car exhausts.

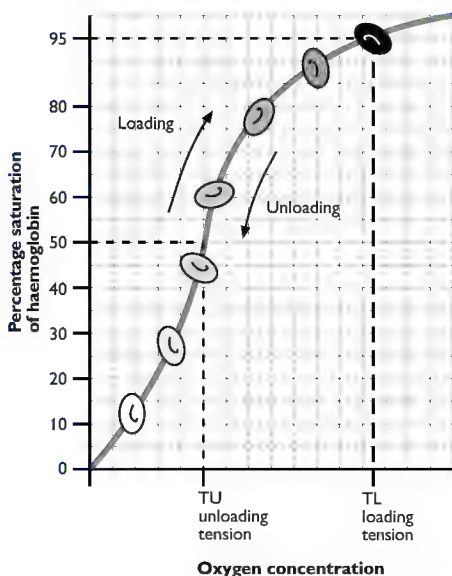
Gas exchange at the tissues is opposite to that at the lungs with oxygen being released and carbon dioxide taken up. Tissues vary widely in their demands for oxygen and in their production of carbon dioxide, particularly during exercise when the muscles become active. The low oxygen partial pressure in the muscles during exercise increases the diffusion gradient between them and the red blood corpuscles, thus encouraging the dissociation of the oxyhaemoglobin and the release of oxygen in solution to diffuse to the tissues.

Some carbon dioxide is carried in the red blood cells in combination with haemoglobin as carbaminohaemoglobin. Some carbon dioxide is carried in the plasma in simple solution, but most is carried as hydrogen carbonate ions in the plasma. Carbon dioxide released as a waste product of cellular respiration enters the red blood cells where the enzyme carbonic anhydrase catalyses the formation of carbonic acid, which dissociates into hydrogen ions and hydrogen carbonate ions. The hydrogen carbonate ions enter the plasma to be carried to the lungs. The release of hydrogen carbonate ions into the plasma from the red blood corpuscles is balanced by the uptake by the red blood corpuscles of chloride ions from the plasma (the chloride shift). When the blood reaches the alveolar capillaries these events are reversed, hydrogen carbonate ions enter the red blood corpuscles, carbon dioxide is released to be breathed out, and chloride ions return to the plasma.

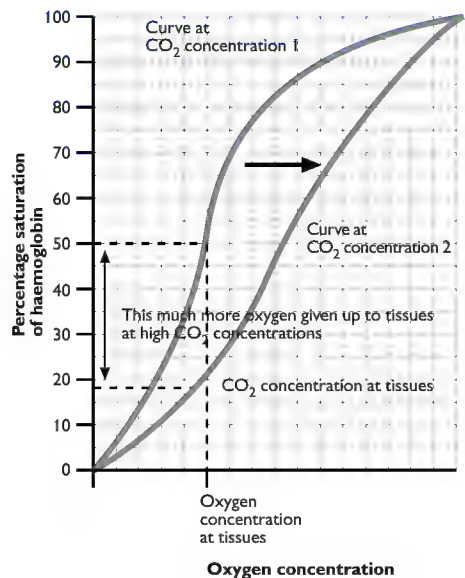
## The EFFECT of CARBON DIOXIDE on OXYGEN TRANSPORT by HAEMOGLOBIN (the BOHR effect)

As has been described the red blood cells are involved in both oxygen and carbon dioxide exchanges and transport, each of which influence each other. At the tissues, the carbon dioxide, produced as a waste product of aerobic respiration in the mitochondria, diffuses in solution down its concentration gradient, from the high  $p\text{CO}_2$  in the mitochondria to the lower  $p\text{CO}_2$  in the blood. The greater the difference in  $p\text{CO}_2$  the greater the amount of diffusion. The formation of carbonic acid (and lactic acid in anaerobic respiration) lowers the pH of the blood. Any increase in acidity (decrease in pH) and/or increase in temperature encourages oxyhaemoglobin to release its oxygen to the tissues. The way in which oxygen is held and released by haemoglobin at different partial pressures can be represented by an oxygen association/dissociation curve, and an increased tendency by oxyhaemoglobin to release its oxygen is shown by the oxygen association/dissociation curve shifting to the right. This effect is called the **Bohr shift** and its significance is that the more active the tissue (e.g muscle) the more carbon dioxide, lactic acid, and heat are produced and the more oxygen is released to that tissue.

Haemoglobin association/dissociation curves

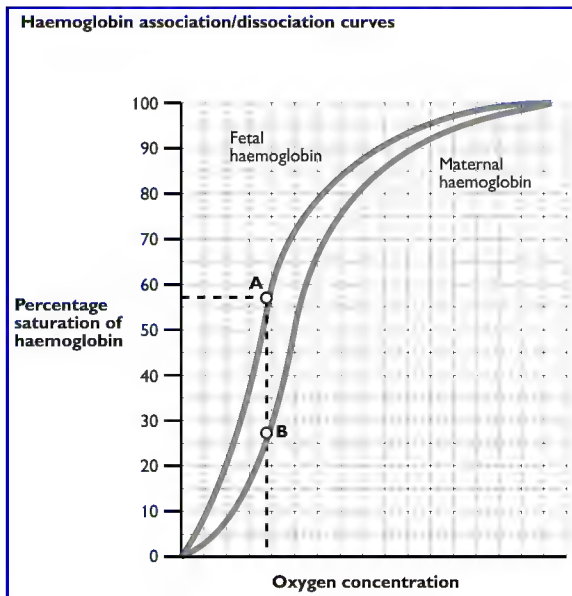


This basic type of curve is altered with differing conditions



## The DIFFERENT AFFINITIES of FETAL HAEMOGLOBIN and ADULT HAEMOGLOBIN for OXYGEN

Fetal haemoglobin is found in the blood of the mammalian fetus. The fetus receives its oxygen from the placenta which is supplied on the mother's side by blood in the uterus wall. In order to take up oxygen from the maternal blood, fetal haemoglobin has a greater affinity (combination potential) for oxygen than adult (maternal) haemoglobin. It also unloads/ dissociates/ gives up it's oxygen at the lower  $pO_2$  which exist in the fetus. In terms of the oxygen association/dissociation curve, the curve for fetal haemoglobin lies to the left of that for adult haemoglobin. After birth, the fetal haemoglobin is gradually replaced by adult haemoglobin over a period of time. There is an inherited condition in which fetal haemoglobin persists throughout life, which causes problems due to its loading and unloading at lower  $pO_2$  than normal.



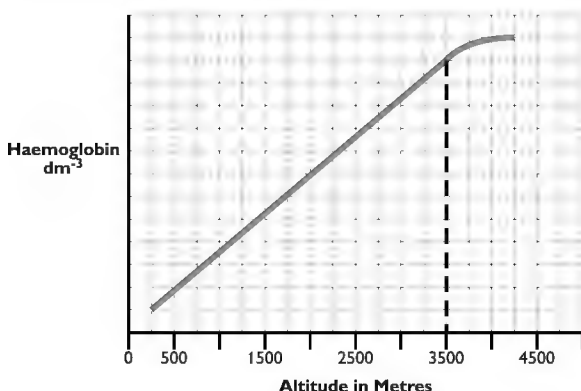
## SIGNIFICANCE of the INCREASE in the RED BLOOD CELL COUNT of HUMANS at HIGH ALTITUDE

At higher altitudes, the  $pO_2$  in air decreases as the air becomes less dense. There is still 21% oxygen in air but as the air is less dense there is a smaller amount of oxygen, therefore at an altitude of about 5500 m, the amount of oxygen in a given volume of air is half that at sea level.

At sea level the red blood cell count is about 5.4 million per microlitre of blood ( $\mu\text{l}$ ) in males and 4.8 million per  $\mu\text{l}$  in females. On arrival at altitude there is a temporary reduction in plasma volume and therefore a temporary increase in the number of red blood cells in a given volume of blood. The total red blood cell count, the red blood cell volume, the total amount of haemoglobin, and the total oxygen carrying capacity of the blood however are not increased by this. After a prolonged (at least several weeks) stay at altitude there is an increase in the red blood cell volume from 35–47% at sea level up to about 60%, and hence a proportional increase in the red cell count and the amount of haemoglobin, with the optimum gains being made at about 3500 m. This increase is stimulated by the release of a factor from the kidneys which increases the production of the hormone EPO which stimulates the red bone marrow to produce red blood cells. Similar increases occur with the artificial use of EPO, which is widely abused by endurance sports people.

The number of muscle capillaries and quantity of myoglobin (a muscle pigment related to haemoglobin but with a greater affinity for oxygen which 'robs' oxygen from oxyhaemoglobin) are also increased. All these changes are typical adaptations to oxygen stress seen in normal aerobic endurance training, but at altitude the oxygen stress is greater. The significance of this increase in the red blood cell count of humans at high altitude is that the greater haemoglobin content can take up more oxygen and thus compensate for the reduced concentration gradient across the gaseous exchange surface of the lungs resulting from the lower levels of oxygen in the thinner air.

Graph to show relationship between altitude and haemoglobin



### ◆ CHECKPOINT SUMMARY

- ◆ Reversible combination of haemoglobin and oxygen to form oxyhaemoglobin is a physical association.
- ◆ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor for exercise.
- ◆ Gas exchange at tissues is in effect the reverse of that at the lungs, and is similarly explained in terms of diffusion gradients (partial pressure gradients).
- ◆ Bohr effect seen when increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ◆ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen.
- ◆ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.
- ◆ Reduction of oxygen partial pressure at altitude stimulates release of EPO hormone which promotes red blood cell production by red bone marrow to compensate for reduced availability of oxygen (reduced partial pressure of oxygen in alveoli).

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## 3.2

### The Mammalian Heart

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#### Content

- ▼ The structure and functioning of the mammalian heart

#### Learning Objectives

Candidates should be able to:

- describe the external and internal structure of the mammalian heart.
- explain the differences in the thickness of the walls of the different chambers in terms of their functions.
- describe the mammalian circulatory system as a closed double circulation.
- describe the cardiac cycle.
- explain how heart action is initiated. (Reference should be made to the sino-atrial node, the atrio-ventricular node and the Purkyne tissue.)

#### Learning Objectives

#### EXTERNAL and INTERNAL STRUCTURE of the MAMMALIAN HEART

The heart is situated slightly to the left of the midline of the chest, protected by the ribs and by a tough membrane (pericardial membrane) which surrounds it in a fluid filled pericardial cavity. The human heart is about 12cm long with an average mass of 300g in an adult man, and 250g in an adult woman.

It is composed of four chambers, two upper thinner walled atria, and two lower thicker walled ventricles. The right and left sides are divided from each other by a septum. The right atrium receives blood in the venae cavae from the body, and the left atrium receives blood in the pulmonary veins from the lungs. (Note that diagrams of internal organs are always viewed from the front of the body, so that the right atrium and right ventricle appear on the left side of the diagram.)

The atria are separated from the main pumping chambers, the right and left ventricles, by flaps of fibrous tissue which act as one way valves. These atrio-ventricular valves differ from each other. The **tricuspid** valve on the right has three flaps, and the **bicuspid** valve on the left has two. These are supported by tendons and muscles which prevent them opening upwards under pressure.

Inside the entrance of the main arteries which leave the heart, the aorta and pulmonary artery, are two more sets of valves called semi-lunar or pocket valves which when filled with blood block the arteries. Immediately above the semi-lunar valve in the aorta is the entrance to the **coronary artery** which supplies the heart muscle with nutrients and oxygen. The artery spreads its branches all over the surface of the heart. Deoxygenated blood is collected into the coronary vein which empties directly into the right atrium. The heart requires its own blood supply despite being filled with blood, as the blood that it is pumping is passing through too quickly, and the heart walls are too thick for diffusion to supply the needs of the heart muscle fibres.



## RELATIVE THICKNESS of the WALLS of the DIFFERENT CHAMBERS

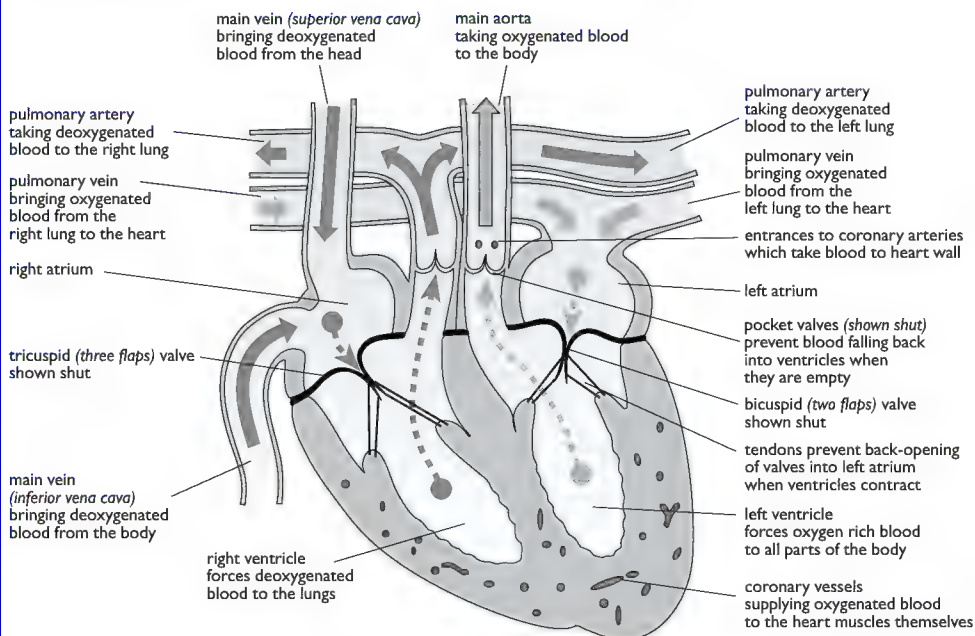
The walls of the atria are less muscular than those of the ventricles, and the wall of the left ventricle is more muscular than that of the right ventricle. These differences reflect the different pressures that need to be generated in the chambers. The atria only have to pump blood into the ventricles. The right ventricle pumps blood to the lungs at a relatively low pressure. The lungs are close to the heart, and too high a pressure could damage the delicate alveoli and result in the filling of the lungs with fluid. The left ventricle must generate a high pressure to pump blood right around the body.

However, it is important to remember that the volumes of the lumens (cavities) of the chambers on the right hand side of the heart are the same as those on the left hand side of the heart, otherwise the right side would not be able to supply the left side with sufficient blood.

### ◆ CHECKPOINT SUMMARY

- ◆ External appearance of heart includes small 'flap-like' atria, coronary blood vessels, fat deposits, and major vessels entering and leaving.
- ◆ Internal structure shows two atria and two ventricles separated by tricuspid and bicuspid valves.
- ◆ Chordae tendinae and muscles preventing back-opening of bicuspid and tricuspid valves when ventricles contract (ventricular systole).
- ◆ Pocket valves at base of pulmonary artery and main aorta prevent backflow of blood into ventricles when they relax (ventricular diastole).
- ◆ Atria walls thinner than ventricle walls.
- ◆ Left ventricle wall thicker than right ventricle wall to pump blood around body (systemic circulation).
- ◆ Right ventricle wall thinner as only has to pump blood via pulmonary circulation around lungs, where reduced pressure prevents formation of tissue fluid in alveoli.
- ◆ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.

### Structure of the heart



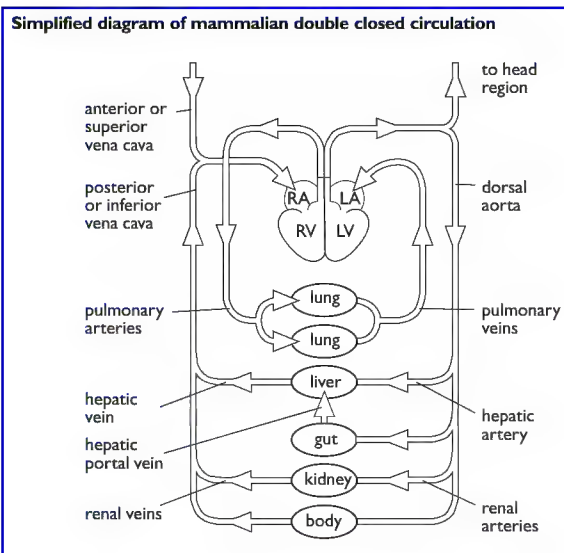
## The CLOSED, DOUBLE, MAMMALIAN CIRCULATION

Closed circulatory systems are those in which the blood flows entirely within a virtually closed system of vessels from the heart in the arteries, arterioles, capillaries, venules and veins back to the heart (although there are invariably some small blood spaces where the blood leaves the vessels e.g. in the liver, and the human placenta). The advantages of a closed circulation are described by contrast with an open circulation. In an open circulation the blood is only enclosed in vessels for part of the circulation and is free in blood spaces in other regions. The blood flow is slow and pressure is low when compared to a closed system. Closed circulations are more efficient than open systems. One of the main advantages of a closed system is that the rate of blood flow, and therefore the transport of materials, is greater. The blood pressure is also higher, which allows for pressure operated kidneys for excretion and the regulation of the composition of the body fluids.

Closed circulations can be either single or double. In single circulation systems the blood only passes through the heart once on each complete circulation of the body. Therefore the blood passes through two sets of capillaries (e.g. in fish, the gills and the body tissues) before returning to the heart. This results in a high resistance to flow, a slow flow, and ultimately a low pressure in the tissues.

The mammalian heart has four chambers divided into right and left 'halves' and blood passes through the heart twice on each complete circulation of the body. This is referred to as a double circulatory system. Double circulatory systems are more efficient than single systems. The blood travels from the heart to the lungs and back to the heart in the **pulmonary circulation**, and then from the heart around the rest of the body and back to the heart in the **systemic circulation**.

**Simplified diagram of mammalian double closed circulation**

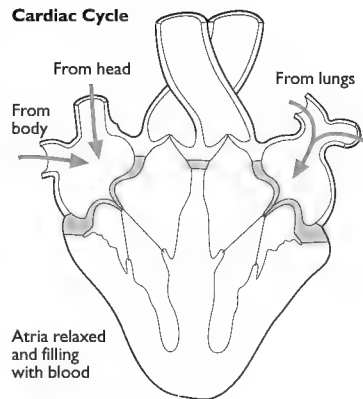


### ◆ CHECKPOINT SUMMARY

- ◆ Closed double mammalian circulation must be compared to open single circulation to understand advantages.
- ◆ Open circulation has blood returning to heart in large open blood spaces (haemocoel), slow flow and low pressure.
- ◆ Compensated for in insects by tracheal system delivering oxygen gas (in air) directly to tissues.
- ◆ Single circulation blood only passes through heart once on each complete circulation of the body, so that blood passes through two sets of capillaries on each circulation (respiratory surface and body tissues).
- ◆ Represents large resistance to overcome before blood returns to heart, resulting in slow flow and low pressure in veins which are typically large blood sinuses to lower resistance to flow.
- ◆ Closed systems blood almost entirely restricted to vessels: arteries, arterioles, capillaries, venules, veins.
- ◆ Tissue fluid exuded to bathe tissues.
- ◆ Double circulation blood passes through heart twice on each circulation.
- ◆ Pressure relatively low to lungs.
- ◆ Pressure raised for systemic circulation to body giving high pressure and fast flow.

This arrangement means that the blood can be pumped through the capillaries of the delicate alveoli of the lungs at a lower pressure, than that of the systemic circulation in which a higher pressure is required for the circulation around the body. The lower pressure is a result of the less muscular wall of the right ventricle, and the lower resistance presented by the relative thinness of the elastic walls of the pulmonary arteries, and their arterioles. If the blood pressure was any higher in the pulmonary circulation (as it sometimes is in people suffering from hypertension or 'high' blood pressure) the lungs would be at risk of filling with tissue fluid, which would have serious consequences for gas exchange. Passage through the pulmonary capillaries further lowers the blood pressure and the return of the blood to the left side of the heart allows the left ventricle to pump the blood powerfully round the body under a raised pressure.

### Cardiac Cycle



## The CARDIAC CYCLE

The sequence of events that occurs during the filling and emptying of the heart is known as the cardiac cycle. At a rate of 70 beats per minute (bpm) the complete cycle takes about 0.86 seconds. It is a continuous sequence of events that occurs simultaneously on the left and right sides, but for the purposes of explanation it is convenient to consider it as occurring in a series of stages

There is a point in the cardiac cycle when all the heart valves are shut, which can be taken as the starting point of the cardiac cycle.

Blood returning under low pressure in the main veins (superior and inferior venae cavae) from the upper and lower body enters the right atrium, and at the same time blood returning from the lungs in the pulmonary veins enters the left atrium.

The atria fill with blood, and the rising pressure of the blood in the atria pushes the tricuspid and bicuspid valves open, and both ventricles begin to fill.

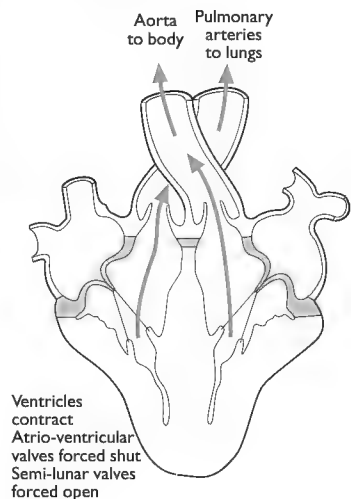
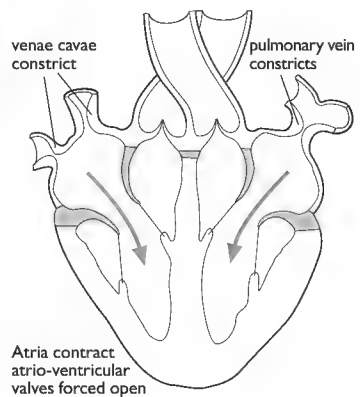
As the heart fills with blood both atria contract (**atrial systole**) forcing even more blood into the ventricles. These are now stretched, and they both contract (**ventricular systole**) forcing the blood upwards.

This upsurge of blood forces the tricuspid and bicuspid valves shut. These valves are prevented from back-opening into the atria by tough tendons, which are held taut by contraction of the papillary muscles to which they are attached. The closing of these valves makes the first heart sound (described as 'lub').

The blood is thus forced along the pulmonary artery to the lungs, and along the main aorta to the rest of the body, pushing open both sets of pocket or semi-lunar valves on the way.

When the ventricles relax (**ventricular diastole**) the blood tends to fall back down the pulmonary artery and main aorta under gravity, thus filling and shutting the pocket valves. The closing of these valves makes the second heart sound (described as 'dup'). All valves are now shut and the cycle is repeated.

The heart sounds can be heard with the use of a stethoscope.



## INITIATION and CONTROL of HEART ACTION

Cardiac muscle is myogenic, that is the stimulus for contraction arises internally, rather than externally from branches of the nervous system, as seen with skeletal muscle.

### Sino-atrial node

The sino-atrial node (SA node) or 'pacemaker' is a mass of specialised tissue in the right atrium from which coordinating waves of electrical activity originate and radiate through the muscle of the heart wall. The sino-atrial node thus coordinates the basic rhythm of the heart contractions.

The wave of excitation spreads rapidly through the interconnected cardiac muscle fibres of the atria allowing both to contract simultaneously. A band of fibrous connective tissue between the atria and ventricles prevents the wave of excitation spreading down into the ventricles.

### Atrio-ventricular node

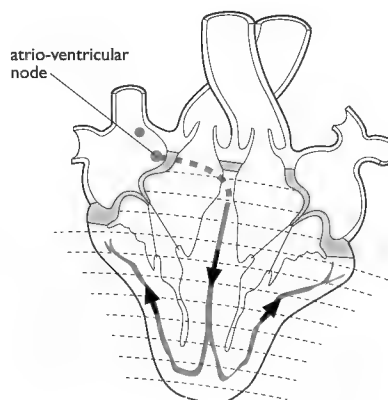
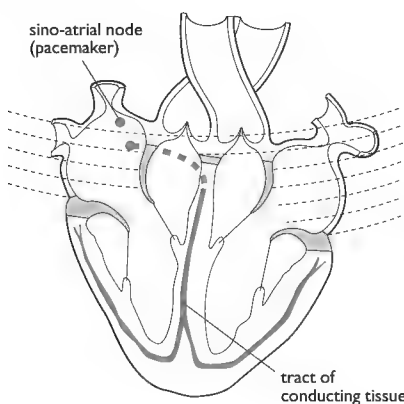
Another mass of specialised tissue, the atrio-ventricular node is located at the bottom of the atria. It is stimulated by the waves of electrical impulses radiating from the SA node, and transmits the impulses through the insulating band of connective tissue between the atria and ventricles. The impulse travels to the base of the ventricles in a tract of conducting tissue, composed of modified cardiac muscle fibres and neurones known as **Purkyne tissue**, from where the impulses radiate upwards through the cardiac muscle of the ventricles.

This pattern of the spread of excitatory waves through the heart, ensures that the atria contract first to force the blood **down** into the ventricles, and that the ventricles subsequently contract to force the blood **up** into the pulmonary arteries and main aorta. The spread of the wave of excitation throughout the heart can be detected by electrodes attached to the skin of the chest and displayed as an electrocardiograph (ECG trace).

ECG trace of electrical activity of heart



### Atrio ventricular node



The onset of strenuous activity can result in ECG abnormalities due to insufficient blood flow to the heart muscle in the first few seconds. This can be prevented by a two minute warm up period before exercise.

Although the SA node initiates contractions of the heart it cannot vary its rate of stimulation on its own. The basic rate of the SA node, can, however, be altered by a variety of influences, over a range from about 30 beats per minute (bpm) to as many as 220 bpm.

It is influenced by the activity of the sympathetic and parasympathetic nerves of the autonomic nervous system, which originate from a control centre in the brain.

The sympathetic nerves secrete noradrenaline, which stimulates an increase in the heart rate (tachycardia) directly.

The parasympathetic nerves, release acetylcholine which causes a decrease in the heart rate (bradycardia). During exercise, the progressive increase in the heart rate is due at first to a decrease in parasympathetic activity, and then to the increasing activity of the sympathetic nervous system.

Also, in response to a general activation of the sympathetic nervous system, adrenaline is released from the adrenal glands, which also increases the heart rate.

Stimuli for these changes include the levels of blood carbon dioxide, pH, and temperature. Increases in these levels, associated with increased activity, result in an increase in the rate of contraction of the heart (beats per minute).

#### ◆ CHECKPOINT SUMMARY

- ◆ Cardiac muscle is myogenic.
- ◆ Rate of contraction modified by SA node (pacemaker) in wall of right atrium.
- ◆ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ◆ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ◆ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from where it radiates up through the walls back to the connective tissue barrier.
- ◆ Detected by electrodes on the skin as an ECG.
- ◆ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline (faster).
- ◆ Demands of body influence cardiac output and therefore blood supply to body.

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## 3.3

### Transport in Multicellular Plants

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#### Content

- ▼ The need for, and functioning of, a transport system in multicellular plants.

Candidates should be able to:

- a) explain the need for transport systems in multicellular plants in terms of size and surface area to volume ratios.
- b) define the term transpiration and explain that it is an inevitable consequence of gaseous exchange in plants.
- c) describe how to investigate experimentally the factors which affect transpiration rate.
- d) describe the distribution of xylem and phloem tissue in roots, stems and leaves of dicotyledonous plants.
- e) describe the structure of xylem vessels, sieve tube elements and companion cells.
- f) relate the structure of xylem vessels, sieve tube elements and companion cells to their functions.
- g) explain the movement of water between plant cells and between them and their environment, in terms of water potential. (No calculations involving water potential will be set.)
- h) describe the pathway and explain the mechanism by which water is transported from roots to leaves.
- i) explain translocation as an energy-requiring process transporting assimilates, especially sucrose, between the leaves (sources) and other parts of the plant (sinks).
- j) describe one possible mechanism of transport in phloem, and the evidence for and against the mechanism.
- k) describe how the leaves of xerophytes are adapted to reduce water loss by transpiration.

#### The need for TRANSPORT SYSTEMS in MULTICELLULAR PLANTS in terms of SIZE and SURFACE AREA to VOLUME RATIOS

As with animals, simply speaking, the larger the plant, the smaller is its surface area to volume ratio. This relationship is used to explain the development of transport systems to supply internal cells far removed from the exchange surfaces with the environment, and to transport materials between different regions of the plant.

Algae e.g. seaweeds, do not have specialised transport systems. Typically Algae are aquatic or semi-aquatic, and absorb water and nutrients over the whole surface. They also tend to be relatively small with large surface area to volume ratios which ensures that all

parts of the plant are close to the surface and can be supplied by diffusion. Some seaweeds have fronds several metres in length which could not be considered as 'small'. However, the fronds are thin and flattened and have a huge surface area to volume ratio.

Terrestrial plants, namely ferns, conifers and flowering plants, have special problems associated with being rooted in the soil with their aerial parts being exposed to the drying atmosphere. They have true roots, stems and leaves, and can reach a very large size. They have transport systems (vascular tissues) running throughout the plant, the xylem and the phloem. Many of these plants can be relatively small, and become secondarily aquatic (e.g. the water lily, Canadian pondweed etc) but still retain their transport systems albeit in a reduced form. Thus it is important to remember that discussions of the development of transport systems also involves the level of complexity of the organism involved.

**Xylem** transports water and inorganic ions from the roots up the stems to the leaves for photosynthesis.

**Phloem** transports sugars (sucrose) mainly from the leaves to the root and shoot tips for their respiration, or to food storage structures in various parts of the plants.

## Learning Outcome (h)

### TRANSPIRATION

Transpiration is the loss of water from the leaves by evaporation. Although a tiny amount of water may be lost directly through the 'waterproof' cuticle of the upper and lower epidermis of the leaves, virtually all transpiration occurs through the stomata of the leaves when they open. Transpiration is an unavoidable consequence of gaseous exchange. As stomata open in the light to take in carbon dioxide for photosynthesis, so water vapour escapes. However, transpiration does have some beneficial effects, it provides a transport stream (transpiration stream) bringing water and mineral ions to the leaves from the roots. It also exerts a cooling effect. Under very hot conditions, however, when the cooling effect is most required, the stomata tend to close, thus stopping transpiration.

#### ◆ CHECKPOINT SUMMARY

- ◆ Principles of relationship between size, shape and surface area to volume ratio hold for plants as previously discussed with animals.
- ◆ In terrestrial plants, transport systems are necessary (independent of  $SA/V$ ) as they are rooted in the soil and have leaves for photosynthesis in the air.
- ◆ Large plants (trees) have large surface area to volume ratios as a result of their leaves, but still have transport systems as diffusion is insufficient to account for the rate of transport throughout the plant.
- ◆ Xylem transports water from roots to leaves.
- ◆ Phloem transports organic compounds (assimilates) e.g. sucrose from sources (leaves or storage organs) to sinks (regions where respiration predominates e.g. growing tips of roots and shoots).
- ◆ Transport in xylem unidirectional.
- ◆ Transport in phloem in both directions.

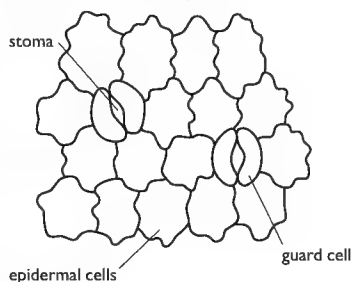
**Factors affecting transpiration** include anything that affects the supply of water to the leaves, and the evaporation of water from the leaves. The main factors are:

- ▼ Availability of soil water determines the supply of water to the plant. Any factor that decreases the availability of soil water will decrease transpiration, which eventually can lead to the stomata closing and in extreme cases to wilting of the plant.
- ▼ Relative humidity is a measure of the water vapour content of the air. The diffusion of water vapour out through the stomata of a leaf only occurs when the relative humidity of the surrounding air is lower than that of the internal leaf spaces. The rate of transpiration increases with decreasing relative air humidity. Relative humidity is dependent mainly on temperature; it decreases as temperature increases. A rise of 10°C doubles the steepness of the humidity gradients from leaf to air, thus increasing transpiration.
- ▼ Air movements increase the rate of water loss by transpiration as molecules of water are carried away from the leaf surface reducing the relative humidity of the air that is immediately surrounding it.
- ▼ Temperature increase provides energy for an increase in evaporation of water from the leaf.
- ▼ Light intensity exerts its main effect directly on the guard cells surrounding the stomata. These are the only cells on the surface of the leaf which possess chlorophyll, and an increase in light intensity typically results in their daytime opening and a consequent increased transpiration rate. Indirectly it will also raise the temperature of the leaf as its radiant energy is absorbed.
- ▼ Stomatal number and size vary widely between species, typically being directly correlated with the availability of water. There are usually more stomata on the lower side of leaves. Some plants (e.g. laurel) have stomata only on the lower side. Grasses having vertical leaves have roughly equal numbers on both surfaces. On average there are about 300 per mm<sup>2</sup> of leaf surface.
- ▼ Stomata allow the uptake of carbon dioxide for photosynthesis but at the same time they control the rate of water loss. Changes in stomatal size affect water loss more critically than carbon dioxide gain, for example if the pore size is reduced, the transpiration rate is reduced more than the rate of carbon dioxide uptake.

#### ◆ CHECKPOINT SUMMARY

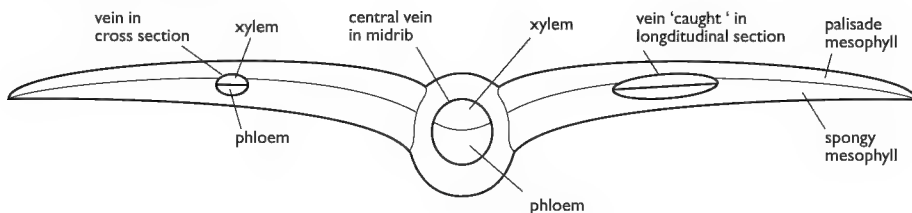
- ◆ Transpiration is the loss of water vapour from the leaves.
- ◆ An unavoidable consequence of having stomata opening for the uptake of carbon dioxide (and release of oxygen) in the light.
- ◆ Evaporation provides upward movement of water column in xylem - the transpiration stream.
- ◆ Transpiration stream provides for upward transport of water and dissolved inorganic ions (and some organic compounds) from roots to leaves.
- ◆ Evaporation from leaves provides some cooling effect, but not when most needed as stomata shut, and leaves wilt in conditions of extreme heat.
- ◆ Transpiration rate affected by any factor that affects evaporation of water: relative humidity, temperature, air speed, availability of water, light intensity, stomatal number, distribution, and degree of opening.

**Surface view of leaf epidermis**

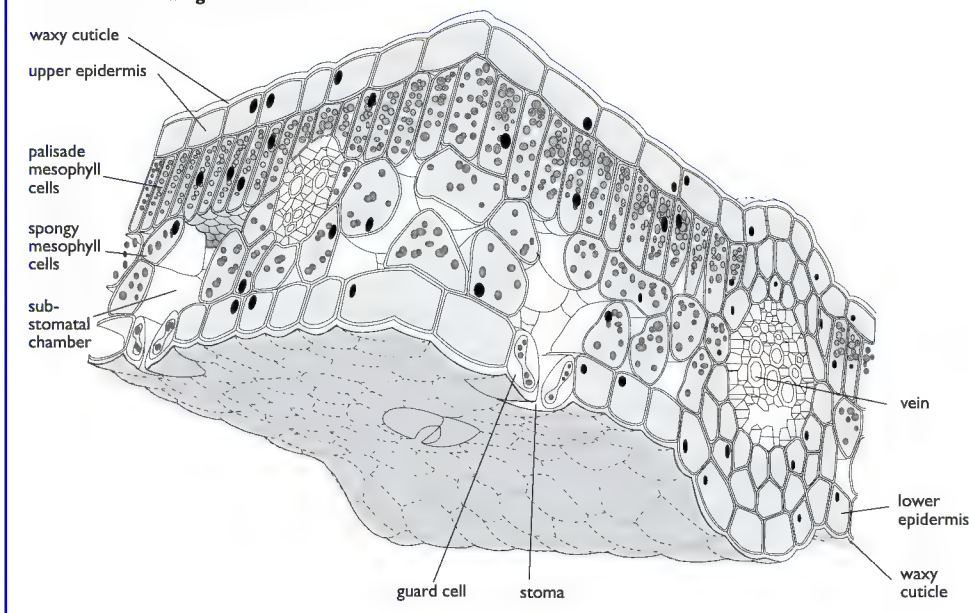




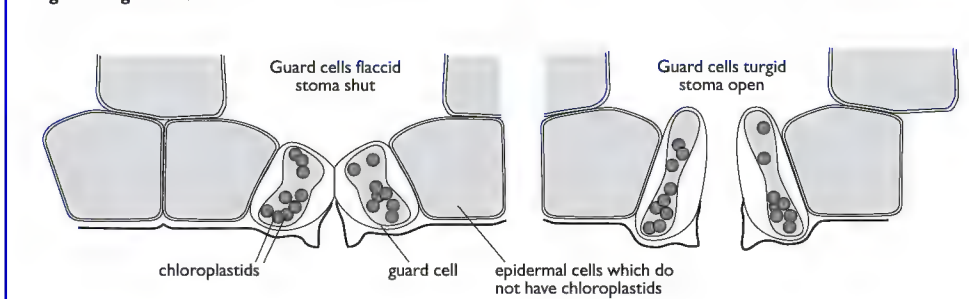
### Low power plan leaf (section)



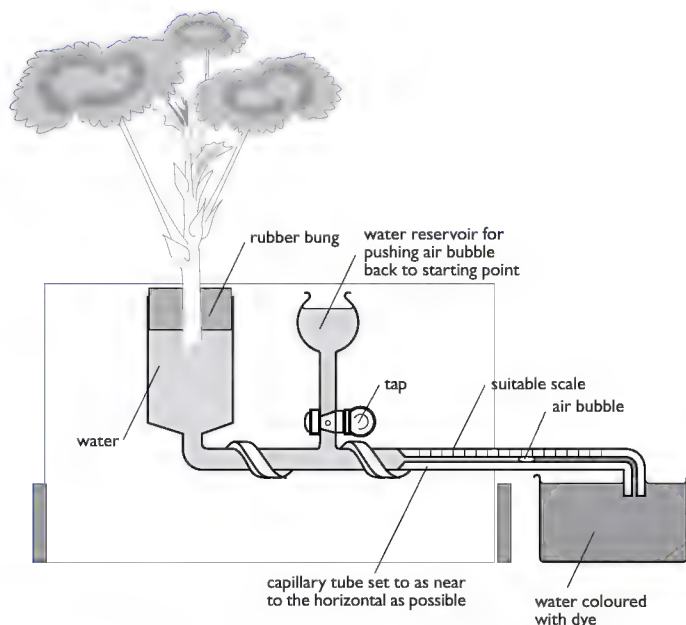
### Section of leaf showing internal structure



### Diagram of guard cell action



## Potometer



### Learning Outcome 1c)

## EXPERIMENTAL INVESTIGATION of FACTORS AFFECTING TRANSPIRATION RATE

Investigations of the effect of many of these factors can be carried out using a simple piece of laboratory equipment, the **potometer**, in which a cut shoot is exposed to different conditions and its water uptake is measured. The rate of water uptake is assumed to be the same as the rate of transpiration, but with a cut shoot the cross sectional area of the cut stem is not as great as the surface area of roots that would normally supply water to that shoot. The transpiration rate from the shoot would therefore be greater if still attached to the rooted plant.

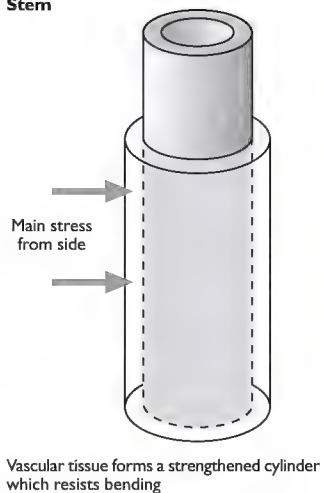
### ◆ CHECKPOINT SUMMARY

- ◆ Transpiration can be measured using a potometer. The principle of which, is that as the water evaporates from the leaves of the shoot an air bubble is drawn along the capillary tube at the same rate - thus giving a measure of the rate of transpiration.
- ◆ Actually it is the rate of water uptake that is being measured
- ◆ In this experiment the cross sectional area of the cut shoot is not as large as the equivalent area of root hairs that would normally supply the leaves, therefore the rate of uptake is less than the rate of transpiration.

## The DISTRIBUTION OF XYLEM and PHLOEM in ROOTS, STEMS and LEAVES of DICOTYLEDONOUS PLANTS

Flowering plants may be classified into two main groups on the basis of the number of their seed leaves (cotyledons), namely the **monocotyledons** with one and the **dicotyledons** with two. There are a wide variety of other features that members of each group have in common including the distribution of xylem and phloem tissues in the vascular bundles in the roots, stem and leaves. As xylem has an important structural and supporting role, the distribution of vascular tissues in the root, stems and leaves reflects the mechanical stresses endured by the particular region. In dicotyledonous plant stems, vascular tissue is arranged in a cylindrical fashion, giving resistance to bending forces created by the wind. In the roots it is concentrated in the centre, resisting pulling forces. (It is interesting to note that aquatic plants species adapted to growing in flowing currents have the stem vascular tissue in the centre, as this best resists the pulling strain of the currents.) In the leaf veins, it ensures that the leaf is supported in a position favourable for photosynthesis.

Stem

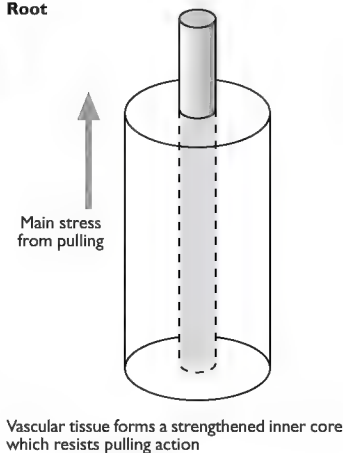


## STRUCTURE and FUNCTION of XYLEM VESSELS, SIEVE TUBE ELEMENTS and COMPANION CELLS

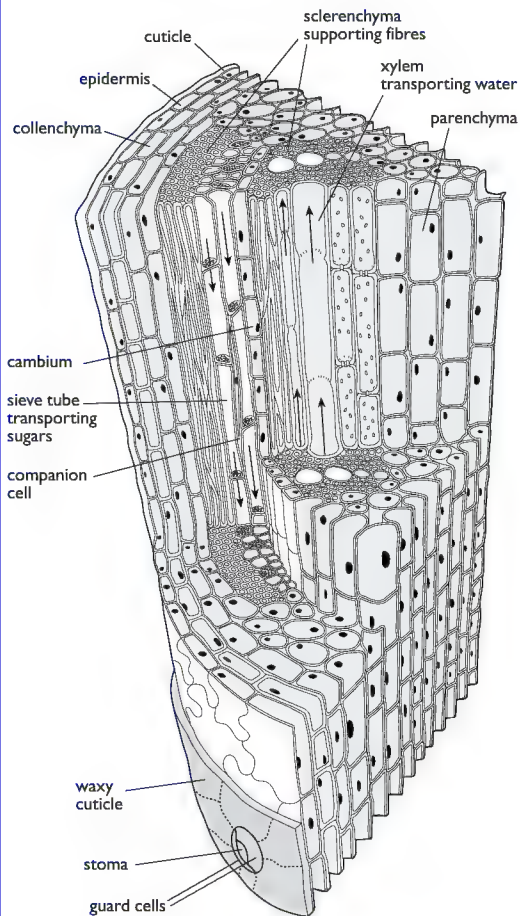
Xylem tissue of flowering plants consists of elongated tracheids and vessels, which have no living contents, and form tubes in which water travels from the roots to the leaves. Tracheids and vessels have strong lignified walls. Lignin is a tough, hard, waterproof substance, and lignified tissue makes up what is commonly known as 'woody tissues' or 'wood'. These lignified tissues are important in supporting the plant. Lignin is waterproof, and this ensures that the water is restricted to the large clear lumen which is produced as a result of the death of the living contents. The strong lignified walls can also withstand the negative pressures which exist inside the the xylem elements as a result of the upward pull of the transpiration stream. The walls are pitted to allow for passage of water through the lignified walls between neighbouring elements of the xylem. Each tracheid (about 5 mm long) has end walls, but in vessels most of the cross walls that were originally present between vessel elements break down, leaving long clear, uninterrupted tubes (up to a metre or more long) with diameters ranging from 20 - 600  $\mu\text{m}$ , allowing much quicker water movement.

Phloem is made up of living sieve tube elements and their companion cells. Sieve tube elements are elongated cells 150 - 1000  $\mu\text{m}$  long with a diameter of 10 - 50  $\mu\text{m}$  which lose their nucleus in the process of maturation, and whose end walls develop into sieve plates with numerous pores. This allows for the passage of materials up and down the long columns of sieve tube elements which run between the roots and the leaves in the vascular tissue. Each sieve tube element is associated with up to six companion cells along its length. These companion cells do have nuclei in their dense cytoplasm.

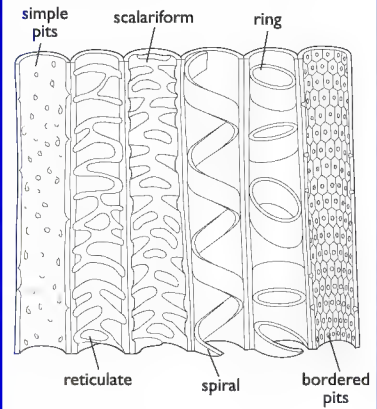
Root



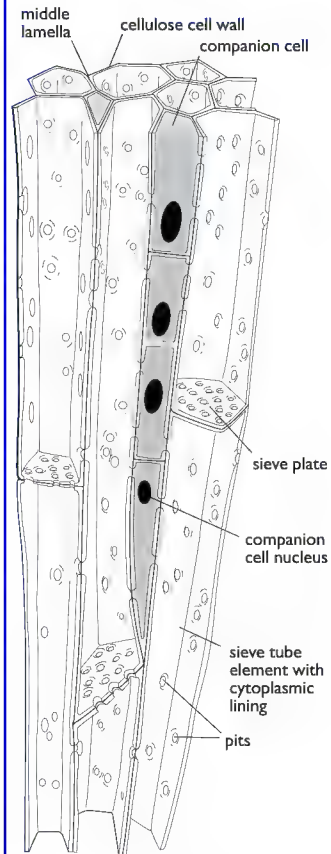
**Diagram of plant stem structure**



**Xylem vessels showing different types of lignified thickening**



**Phloem Cells**



## MOVEMENT of WATER between PLANT CELLS and between them and their ENVIRONMENT in terms of WATER POTENTIAL

In plant cells a non-living cellulose cell wall surrounds the cell surface membrane. The cell wall is freely permeable to water and dissolved substances (solutes.) By contrast, the cell surface membrane is partially permeable, restricting the movement of solutes but allowing water to diffuse in and out more freely. Where a solution is separated by a partially permeable membrane from pure water or a solution of different concentration, the movement of solutes by diffusion is restricted and water will diffuse into the more concentrated solution until equilibrium is reached. The special case of the diffusion of water across a partially permeable membrane is known as **osmosis**.

Water moves into and out of the cell protoplast according to the relative numbers of water and solute molecules on either side of it. The water potential of a fluid is measured in relation to pure water. If the fluid is pure water, there is no movement, so the **water potential of pure water is zero**. The water potential of any solution is less than pure water and is therefore negative. The more negative the water potential the greater the tendency of water to move into that system.

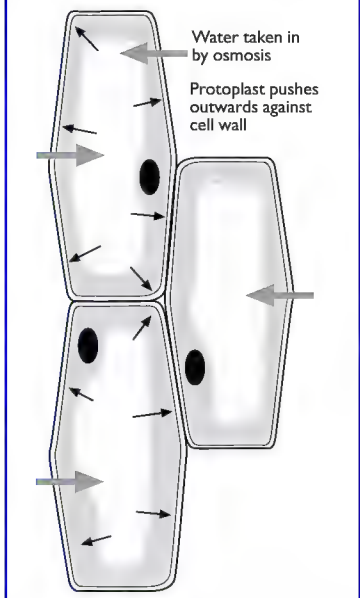
Water will always tend to move from regions of high water potential to regions of lower water potential. Where a plant cell is surrounded by a solution with a higher water potential than that of the cell contents (protoplast), water will move into the cell. As it does so, the cell contents expand until this tendency is counterbalanced by the force exerted by the stretched cell wall. At this equilibrium point the cells are described as fully **turgid**. In a well watered plant, the turgid cells exert pressure on each other making the whole structure rigid (especially the spongy mesophyll in leaves.) Loss of water causes a loss in turgor, the cells become **flaccid**, and the leaves wilt.

In the very unusual case of the surrounding water having a lower water potential than the plant cells (for example, where the soil is flooded with salty water) water will move out of the cell by osmosis so that, in extreme cases the membrane shrinks away from the cell wall. Cells in this state are said to be **plasmolysed**. (Note that all plasmolysed cells are flaccid, but not all flaccid cells are plasmolysed.)

All these considerations affect the movement of water between plant cells and between them and their environment. For example root hair cells gain or lose water in relation to the relative water potentials of their contents and the soil solution, and leaves lose water to the atmosphere according to the same principles.

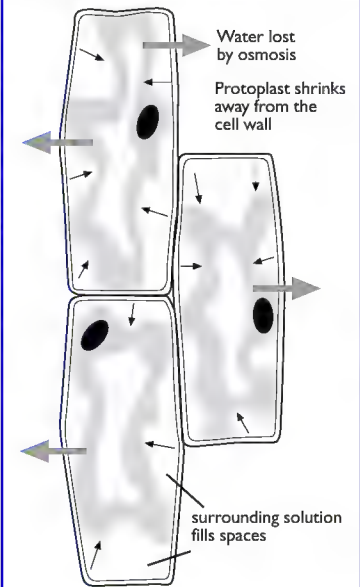
### Turgid Cells

Surrounding solution has lower water potential than protoplast



### Plasmolysed Cells

Surrounding solution has higher water potential than protoplast





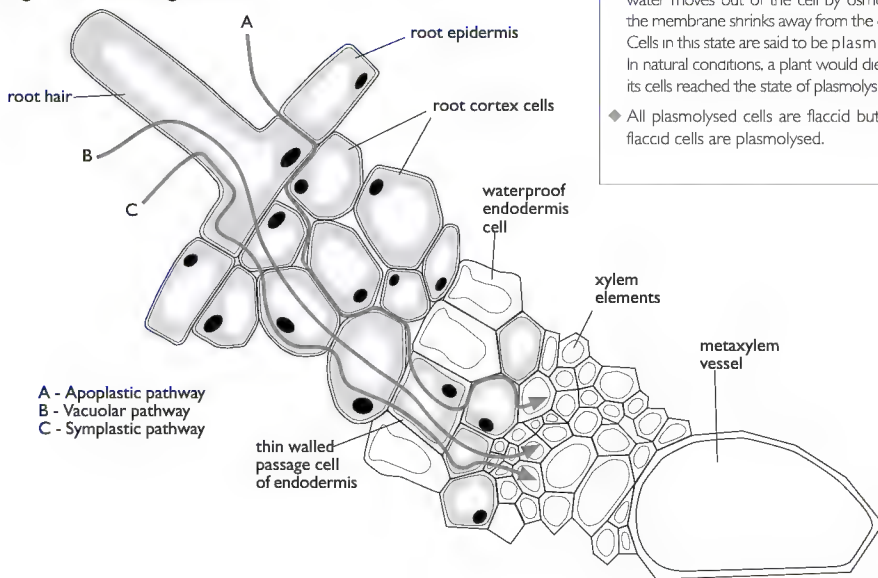
## PATHWAY and MECHANISM of WATER TRANSPORT from ROOTS to LEAVES

Transpiration provides the main force for water transport from root to leaf. At the other end of the plant, water is taken up by the root hair cells which occupy a small region just behind the growing tips of new roots. Root hairs take up mineral ions by active transport, an energy-requiring process, against the diffusion gradient. This leads to accumulation of ions in greater concentrations inside the plant than in the soil solution. If roots are starved of oxygen, as may happen if the soil is flooded, then mineral uptake will stop, as the production of ATP in respiration for active uptake requires oxygen. This has a consequence for water transport because it is the active uptake of mineral ions which provides the gradient along which some water passively enters the root.

There are three main pathways of water movement across the root to the xylem in the centre. Two involve movement of water from cell to cell down a water potential gradient as the contents of adjacent cells become successively diluted by the incoming water. One of these, the **vacuolar pathway** involves the movement of water through the cytoplasm and the vacuoles and their membranes. The other involves the movement of water through the cytoplasm avoiding the vacuoles and their membranes, the **cytoplasmic pathway**. Both these are high resistance pathways as they involve water moving through the cytoplasm and membranes.

The vast majority of water, however, is pulled in directly by the transpiration stream acting through a continuous system of water between the soil solution and the xylem travelling in the porous cellulose cell walls of the cells, the **apoplastic pathway**. This is a pathway of low resistance as the water does not enter the cells as such.

### Passage of water through the root



### ◆ CHECKPOINT SUMMARY

- ◆ The cell membrane is partially permeable allowing water molecules to pass through it but not most solute molecules.
- ◆ The cell wall is freely permeable to everything.
- ◆ As partially permeable membrane prevents free diffusion of solute molecules, water moves by osmosis down a water potential gradient.
- ◆ Water potential is a measure of the tendency to gain or lose water in relation to pure water. If the fluid is pure water there is no movement and the water potential is zero.
- ◆ The presence of solutes slow the movement of water molecules giving any solution a negative water potential at normal pressures.
- ◆ Water will move from regions of high to low water potential (from less negative to more negative values).
- ◆ Plant cells in solutions (or water) more dilute than their contents gain water by osmosis and the cell contents expand until this force is counterbalanced by the force exerted by the stretched cell wall. At this equilibrium point the cells are described as turgid. In a well watered plant, the turgid cells exert pressure on each other making the whole structure rigid.
- ◆ Loss in water causes a loss in turgor, becoming flaccid, resulting in wilting of leaves.
- ◆ If the water potential of the cell contents is greater than that of the surrounding solution water moves out of the cell by osmosis and the membrane shrinks away from the cell wall. Cells in this state are said to be plasmolysed. In natural conditions, a plant would die before its cells reached the state of plasmolysis.
- ◆ All plasmolysed cells are flaccid but not all flaccid cells are plasmolysed.

Water and dissolved solutes move up the stem in the xylem tissue. The generally accepted explanation of the mechanism for the upward transport of water is known as the **cohesion-tension** mechanism. It is based on purely physical forces and does not involve the activities of living cells. Evaporation through the leaf pores or stomata causes a gradient of water potential across the mesophyll cells of the leaf, and a direct force on the water in the porous cellulose cell walls which causes water to be withdrawn from the xylem. Cohesive forces between water molecules result in a column of water being drawn up the plant xylem as the water evaporates from the leaves. This transpiration 'pull' generates a tension which results in the sap being under a negative pressure. It can produce a measurable decrease in stem diameter (and even trunk diameter) when transpiration is high. The water column is supported and prevented from falling back down under gravity in the xylem elements by adhesion to the lignified walls of the xylem elements. A continuous water column is necessary for this mechanism, and any breakages caused by storm damage or freezing (which forces air out of solution) can be by-passed via the system of lateral pits in the lignified walls. In woody plants only the most recently formed 'sap wood' functions in water transport, and the remaining 'heartwood' is used as a depository for waste products (but it is still important in support).

## Unit 11

### TRANSLOCATION OF ASSIMILATES especially SUCROSE

**Translocation** is the name given to the energy-requiring process in which organic materials synthesised by the plants, particularly sucrose are transport in the phloem sieve tube elements.

Organic substances synthesised by plants are also known as **assimilates**, as they have been synthesised (assimilated) from simple inorganic substances.

#### Translocation from sources to sinks

The transport of sucrose and other organic compounds occurs from the point of origin or '**source**' of the organic material to the point of destination or '**sink**'. Typically the main 'source' of sucrose are the photosynthesising leaves. Transfer cells found next to sieve tubes, especially in small leaf veins, have a characteristic dense cytoplasm and many organelles, and appear to be involved in transferring substances to and from the sieve tubes of the phloem. The main 'sink' is the respiring roots. However, other 'sinks' are shoot tips, fruits and seeds, and food storage organs e.g. tubers and bulbs, in the autumn. Tubers and bulbs can in turn act as 'sources' and the growing shoots and leaves as 'sinks' in the spring. Thus, transport of sucrose and other organic compounds in the phloem can be in two directions, unlike the xylem where transport of water is only in one direction from the roots towards the leaves. If the 'source' is in the roots and the 'sink' is in the aerial parts, then some organic material can move in the transpiration stream up the xylem.

#### ◆ CHECKPOINT SUMMARY

- ◆ Transpiration in the leaves generates the major force for the upward movement of water in the transpiration stream.
- ◆ Root hairs actively take up inorganic ions and water follows passively down a water potential gradient generating a root pressure.
- ◆ Root pressure can only account for a rise of a few metres but could be important before leaves are fully open in the spring in temperate climates.
- ◆ Three main pathways of water movement across the root, are the vacuolar pathway, the cytoplasmic pathway, and the apoplastic pathway.
- ◆ Once in the xylem, capillary aids rise of water, but main force is generated by transpiration at the leaves.
- ◆ Cohesion prevents breakage of continuous water column as it is pulled up under negative pressure (tension).
- ◆ Adhesion to the walls of the xylem support the water column.
- ◆ Breakages (air bubbles) caused by frost and/or wind damage can be by-passed via pits in lateral walls of xylem tracheids and vessels.
- ◆ Endodermis passage cells are the only point where water must pass through cell surface membranes on its passage through the plant.

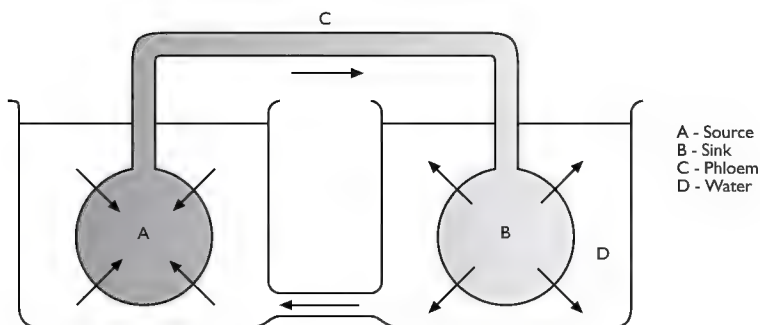
#### ◆ CHECKPOINT SUMMARY

- ◆ Translocation of assimilates (organic substances synthesised in the plant) e.g. sugars, amino acids, hormones, nucleic acids etc. occurs in the phloem tissue.
- ◆ Organic materials move from an area of manufacture (source) to an area where they are used (sink). Sucrose thus moves from the leaves (sources) to actively growing and respiring regions such as the roots, flowers, and new buds (sinks).

## MECHANISM of TRANSPORT in PHLOEM

Diffusion is not sufficient to account for the observed rates of flow in the phloem which are many times faster than could be explained by diffusion alone. The pressure flow (**mass flow**) mechanism suggests that the 'source' regions have a lower water potential than the 'sinks', due to the presence of greater concentrations of solutes, such as sucrose. This results in water uptake and an increased turgor within the cells at the source. As a result of this and the fact that the two regions are in direct cytoplasmic contact, it is suggested that the organic materials are forced along the resultant hydrostatic pressure gradient, for example from leaves to roots. The flow is maintained by active pumping of sugars into the sieve tube elements in the leaves by companion-transfer cells, and their removal at the 'sink' as a result of their use (e.g. in respiration or conversion to insoluble starch).

### Mass flow diagram



### Evidence for this mechanism

Aphids (greenfly) feed specifically on living phloem by means of their long tubular mouthparts which they can insert directly into the phloem sieve tube elements. If they are knocked off whilst feeding, their mouthparts are left protruding from the phloem, and the sugary contents, referred to as 'honey dew' exude out of the broken ends for periods as long as several days in volumes up to 100 000 times the volume of the one penetrated sieve tube element. This demonstrates that the contents of the sieve tube elements are indeed under positive pressure as the mechanism would require (in contrast to the negative pressure of the contents of the xylem elements) and that the flow is significant. On a larger and less precise scale, cut phloem in large woody plants can exude sucrose rich sap in volumes up to many litres ( $\text{dm}^3$ ) per day.

Direct measurements of the pressure within the sieve tube elements indicate that the pressure gradients between sources and sinks are in the right direction and great enough to account for the mass flow of sugars over the largest distances required in the tallest trees.



## Evidence against this mechanism

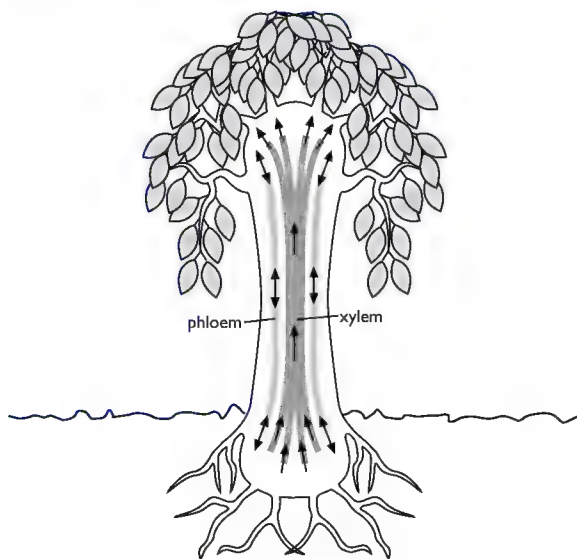
Evidence against this mechanism is provided by radioactive tracer studies which indicate that substances move in different directions at the same time (although this could be occurring in different sieve tube elements, which would still be explicable in terms of the mass flow theory).

Also the movement is not simply from source to sink. Mature leaves kept in the dark, unable to photosynthesis and supply their own sugars for respiration, fail to import sugars and eventually die. This observation supports the suggestion that the growth substance auxin is in some way involved. Mature leaves have low auxin levels, whereas virtually all 'sinks' are actively growing tissues e.g. root tips, food storage organs and apical meristems and have high auxin levels. Furthermore, when auxins are applied artificially to a region of a plant the flow of sucrose in the phloem is redirected towards it.

Observations that translocation relies on the activities of living cells, argue against the simple mass flow mechanism, which could operate more easily through dead empty elements like the xylem, as long as the loading and unloading regions were living. These observations include the following:

- ▼ translocation only occurs in young phloem sieve tube elements with actively streaming cytoplasm;
- ▼ metabolic poisons (e.g. those inhibiting respiration) inhibit translocation;
- ▼ when the phloem tissue is killed with heat or poisonous substances translocation stops;
- ▼ companion cells are metabolically active along the length of the sieve tube elements.

### Mass flow in xylem and phloem



NB. Movement in the phloem can occur in both directions

#### ◆ CHECKPOINT SUMMARY

- ◆ Phloem tissue (unlike most of the Xylem) is composed of living cells and elements.
- ◆ Mechanism of movement still not fully understood.
- ◆ Mass flow mechanism postulates high hydrostatic pressure in sources and low in sinks.
- ◆ Contents are under positive pressure.
- ◆ Movement occurs in both directions.
- ◆ Movement of assimilates is stopped if the phloem is poisoned with a respiratory inhibitor; or exposed to high or low temperatures, i.e. translocation is an active process, only occurring in those sieve tube elements showing cytoplasmic streaming.

## XEROPHYTIC ADAPTATIONS to REDUCE WATER LOSS by TRANSPIRATION

Plants adapted to growing in conditions of water shortage are known as xerophytic plants or xerophytes. This group includes plants from desert regions, as well as those in temperate regions on rapidly draining sandy soils.

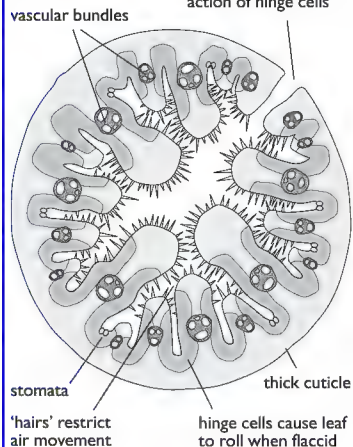
The main way in which terrestrial plants lose water is by evaporation from their leaves, a process known as transpiration. Some water is lost in this way over the whole leaf surface through the cuticle (cuticular transpiration), but most is lost through the stomata, which typically open in the light for the absorption of carbon dioxide for photosynthesis. Xerophytes show many structural adaptations of the leaves which decrease the rate of transpiration, and individual species can show any combination of these adaptations.

- ▼ Thickened waterproof cuticle reduces water loss through the surface of the leaf, especially on the upper surface of the leaf which is most exposed to air currents and heat absorption from sunlight, both of which increase the rate of evaporation of water from the leaf in transpiration; e.g. laurel leaves.
- ▼ The surface of the leaf may be 'hairy' (not true hairs) which protect the stomata from air currents which would otherwise increase transpiration e.g. 'Viper's Bugloss' (*Echium vulgare*).
- ▼ Stomata can be sunken in pits and grooves, which protects them from air currents, e.g. on pine 'needles'.
- ▼ Stomata can be reduced in number, especially on the upper surface of the leaves, where the exposure to the heat of the sun and air currents is the greatest, indeed some e.g. laurel, have no stomata on the upper surface.
- ▼ Leaves can have a reduced surface area, which also reduces the number of stomata, e.g. pine 'needles'; and gorse and cacti where the leaves are reduced to spines and photosynthesis is carried out by the green stems.
- ▼ Leaf folding or rolling reduces water loss through the stomata by protecting them from air currents, and enclosing them in a zone of high humidity, e.g. sand dune grass (*Ammophila*), where the long ridged leaf rolls up along its length at times of excessive transpiration.
- ▼ Leaves can be succulent, with tissues where water can be stored for periods of drought, e.g. cacti.
- ▼ Cells of the leaves have mucilage and can withstand dehydration for longer periods than those of non-xerophytes (mesophytes).
- ▼ Leaf fall stops transpiration. Deciduous plants lose their leaves with the onset of winter in temperate regions, when the low temperatures inhibit water uptake by the roots, (you may have noticed that some of the xerophytes mentioned above (pine and laurel) are 'evergreens', i.e. they do not have to lose all their leaves in winter as they have a low transpiration rate). Some plants lose their leaves in dry periods for the same reason, and photosynthesis is carried out by their green stems e.g. broom.

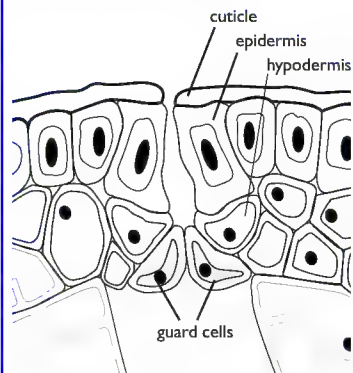
### Marram Grass T.S.

Cross section leaf of *Ammophila* (sand-dune grass) or Marram Grass

edges of leaf almost meet to form narrow opening to dry air, opening alters through action of hinge cells



### Pine Needle Stomata



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# Topic Guides



**1.1 Cell Structure**

**1.2 Biological Molecules**

**1.3 Enzymes**

**1.4 Cell Membranes and Transport**

**1.5 Genetic Control of Protein Structure and Function**

**1.6 Nuclear Division**

**1.7 Energy and Ecosystems** © FELTHAM PRESS

## 1.1

### Cell Structure

#### Learning Outcomes (LO)

**Explain and distinguish between resolution and magnification with reference to light and electron microscopy**

#### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Resolution is the ability to see detail.
- ▼ The higher the resolution the more of the detail present can be seen.
- ▼ Magnification is enlarging in size.
- ▼ Increasing magnification only reveals extra detail if the detail can be resolved.
- ▼ Resolving power of light microscope is limited by the wavelength of light.
- ▼ Put simply some detail is so small that it cannot be 'hit' by light, and therefore cannot be seen.
- ▼ Endless magnification of the image produced by a light microscope yields no extra information.
- ▼ Wavelengths of electron beams are much shorter than that of light and give the electron microscope much greater resolving power.
- ▼ Therefore extra magnification up to x 250 000 yields an equivalent amount of detail.

### Student Activity

#### Materials

- Microscope
- Electron micrographs
- Prepared slide of TS dicotyledonous leaf
- OHT Magnification and Resolution

#### Procedure

Set up slide of TS Leaf showing xylem on high power  
Although this may be the first sight of TS dicotyledonous leaf, it can clearly be seen to be made up of cells.

Even under the highest power (x400) very little detail will be seen within the cells.

□ OHT Magnification and Resolution.

Measure the size (diameter) of a mitochondrion on the electron micrograph and calculate the actual size by dividing by the magnification.

#### Set work

1. Distinguish between the terms "magnification" and 'resolution'.
2. Why can more detail be seen using a beam of electrons than using visible light?
3. Why can't living specimens be viewed under an electron microscope?
4. Explain the difference between scanning and transmission electron microscopes.

Notes: \_\_\_\_\_

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## 1.1

### Cell Structure

Learning Outcomes: 1.1.1

**Describe and interpret drawings and photographs of typical animal and plant cells as seen using the light microscope**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Cell differentiation and specialisation prevent the easy definition of typical animal and plant cells.
- ▼ 'Typical' cells would be those considered to show features common to the vast majority of cells in animals or plants
- ▼ A squamous (pavement) epithelium cell from the lining of the mouth could be considered as a 'typical' animal cell.
- ▼ A mesophyll cell from a leaf could be considered as a 'typical' plant cell.
- ▼ Under the best light microscope both the typical animal cell and the typical plant cell can be seen to possess a cell surface membrane, cytoplasm, nucleus with nucleolus, mitochondria, endoplasmic reticulum, and Golgi body.
- ▼ In addition the typical plant cell can be seen to possess a cell wall around the cell surface membrane, a large central vacuole surrounded by the tonoplast membrane, and chloroplasts.

### Student Activity

Notes: \_\_\_\_\_

#### Materials

- Microscopes
- Slides of squamous epithelium
- Slides TS Leaf showing palisade cells
- Practical work sheet 1:  
**Drawing plan diagrams of tissues and calculation of linear magnification using the light microscope**

#### Procedure

Make LP and HP drawings of the plant and animal cells.

Note the major differences:

- a) in what you actually see;
- b) what you know from your theory studies.

Explain the reasons for differences between (a) and (b)

#### Set Work

Write a brief justification of 'interpretation' in Biological drawing, e.g. drawing the plant cell wall as a double line (which is not actually seen down the typical lab microscope).

## 1.1

### Cell Structure

#### Learning Outcomes (LO)

**Describe and interpret drawings and photographs of typical animal and plant cells as seen using the electron microscope**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ A 'typical' animal cell under the electron microscope (EM) is the mammalian liver cell, as it contains a representative selection of those organelles found in animal cells.
- ▼ A 'typical' plant cell under the EM is a leaf mesophyll cell.
- ▼ The risk of distortion (production of artefacts) is greater with the EM as a result of the total dehydration, very thin sectioning, staining, and high temperatures generated.
- ▼ It has been argued that the rough endoplasmic reticulum is an artefact caused by the cracking and splitting of the cytoplasm pushing the ribosomes to the edges of the cracks.
- ▼ Mitochondria are rod-shaped organelles but appear oval in cross section. Chloroplasts are oval in structure and appear oval in cross section
- ▼ Lysosomes cannot be identified solely on appearance, the activity of digestive enzymes must be demonstrated by other means.
- ▼ The rough and smooth endoplasmic reticula are not related in structure or function, and are not joined. Typically there is less smooth endoplasmic reticulum in plant cells.
- ▼ Controversy surrounds the identification of centrioles in plant cells.

### Student Activity

#### Materials

- A selection of e.m.s showing whole cells or parts of cells, both animal and plant.
- T.E.M. image of a whole cell (unlabelled, for homework)
- OHT Ultrasound scan of fetus in uterus

#### Procedure

- OHT Ultrasound scan of fetus in uterus demonstrates that something imaged in an unfamiliar way requires practice to interpret.

Examine the ems in a critical manner.

Is it plant or animal? Look at the junction between adjacent cells. Is there a cell wall? Any large spaces?. Look to identify the larger things first, e.g. nucleus, mitochondria, chloroplasts.

Discuss clues which point to particular functions e.g. lots of mitochondria, cilia, microvilli etc.

#### Set work

- a) Label the T.E.M. of an animal cell before the next lesson.
- b) Try to find an explanation of the fact that the sac-like cisternae of the rough endoplasmic reticulum is virtually always seen in cross section

Notes: \_\_\_\_\_

## Learning Goals 74

## Topic Guide

Session:

- ▼ Functions of organelles determined by differential centrifugation, and biochemical investigation of samples from each 'organelle band'.
- ▼ Centrifuged 'organelle bands' not completely 'pure'.
- ▼ Lysosomes poorly identifiable in electron micrographs, their identification is based almost entirely on functional criteria.
- ▼ Radioactive tracers can locate functions in specific organelles.
- ▼ Cells specialised for particular functions show organelles developed in similar way, e.g. active voluntary muscle, and secretory cells, have increased number of larger mitochondria.

- ## Student Activity

- A selection of electronmicrographs showing whole cells or parts of cells, both animal and plant.
- T.E.M. image of a whole cell labelled for previous Set Work

Revise the identification of all organelles and membrane systems.

Construct a table of organelles and their function.

Explain the structure and function of a mitochondrion in relation to its surface area to volume ratio.

Notes:

## 1.1

### Cell Structure

Learning Outcomes (LO)

**Describe the structure of a prokaryotic cell and compare and contrast with eukaryotic cells**

### Topic Guide

Session:

#### Check List

- ▼ Prokaryotic cells (bacteria) lack a true nucleus and membrane bound organelles.
- ▼ The DNA is located in a central strand, and as circular plasmids in the rest of the cytoplasm.
- ▼ The cell wall is not cellulose as in plant cells.
- ▼ Respiration is located in mesosomes which are infoldings of the cell surface membrane, sharing the principle of increased surface area of membranes with true mitochondria.
- ▼ The origin of mitochondria and chloroplasts as mutualistic prokaryotes with eukaryote cells, explains their absence in prokaryotes.
- ▼ Ribosomes present in both prokaryotes and eukaryotes.
- ▼ Prokaryotic cells may form colonies but never multicellular organisms/tissues.
- ▼ Eukaryotes do have a true membrane bound nucleus containing chromosomes of DNA and histone proteins, and membrane bound organelles as described previously.
- ▼ Eukaryotic cells typically form tissues in multicellular organisms.

### Student Activity

#### Materials

- Microscopes
- Slides of bacteria, and of squamous epithelium
- OHT Prokaryotic cell

#### Procedure

Observe the two slides under the microscope.

Make a drawing of the squamous epithelium cells and then draw the bacteria as seen down the light microscope ON top of the drawing of the squamous epithelium cells

Look at their relative sizes and relate this to the fact that many bacteria are disease causing (pathogenic).

Compare what you have seen down the microscope with the □ OHT Prokaryotic cell, and comment on the relative resolution and magnification of the electron microscope when compared to your light microscope.

#### Set work

Much of the original work on the function of DNA was done on prokaryotic cells, write a paragraph suggesting difficulties in extrapolating (extending) the findings of this work to eukaryotic cells.

Notes:



## 1.1

### Cell Structure

#### Learning Outcomes (LOs)

**How cells are organised into tissues with reference to squamous and ciliated epithelia, xylem and phloem.**

#### Tissues and organs

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ In multicellular organisms cells are organised into tissues. A tissue being an association of similar cells specialised and coordinated to a particular function. Some functions being more specialised than others.
- ▼ Examples of tissues in mammals include squamous epithelium covering surfaces e.g. in the Bowman's capsule of the kidney tubule and the alveoli of the lungs, ciliated epithelium lining the trachea and bronchi, cerebro-spinal canal, and oviduct.
- ▼ Examples of tissues in plants include the transport tissues (vascular tissues) xylem (wood) and phloem.
- ▼ Some tissues consist of only one type of cell. e.g. ciliated epithelium, whilst others consist of several variants of similar types of cells, e.g. phloem tissue consists of sieve tube elements, companion cells and phloem parenchyma.
- ▼ Cells in the same tissue develop from the same original cell type, even though the fully differentiated cells may appear very different, e.g. xylem vessels and xylem parenchyma.
- ▼ Organs are composed of different tissues specialised to particular functions, e.g. a lung is an organ and consists of squamous epithelium, ciliated epithelium, connective tissue, blood vessels etc.
- ▼ Organs are not so clearly defined in plants but the leaf can be considered as an organ of photosynthesis, consisting of epidermal cells, mesophyll cells, and vascular tissue etc.

## Student Activity

### Materials

- Microscopes
- Slides of TS lung
- Slides of TS leaf
- Practical work sheet 1:  
**Drawing plan diagrams of tissues and calculation of linear magnification using the light microscope**

- ☐ OHT TS lung and TS leaf

### Procedure

View the prepared slides, first on low power to identify the major regions.

- ☐ OHT TS lung and TS leaf aids interpretation.

Make a drawing to show the arrangement and distribution of the tissues. DO NOT DRAW ANY CELLS, just the outline of the tissues. Label in pencil with neat lines and include the magnification. The drawings should be at least half a side of plain A4 in size.

### Set work

- a) Write a paragraph suggesting reasons why organs are more numerous and clearly defined in animals than in plants.
- b) Make a list of as many tissues and organs that you can think of in the human body and a flowering plant.

Notes: \_\_\_\_\_



## Biological Molecules

## Topic Guide

Session:

**Tests for reducing and non-reducing sugars, iodine test for starch, emulsion test for lipids, and biuret test for proteins**

## Check List

- ▼ Generally all these tests are qualitative, i.e the results show whether a substance is present or not.
- ▼ They are not generally quantitative, i.e. the results do not give an accurate measure of how much of the substance is present.
- ▼ The Benedict's test for reducing sugars can be semi-quantitative in so much as the colour and amount of the precipitate found in a positive test is proportional to the amount of reducing sugar present. Positive results can be compared to results from solutions of known concentration of reducing sugar.
- ▼ The same considerations apply to the iodine in potassium iodide test for starch. The colour for a positive test grading from blue-black to pale brown with decreasing amounts of starch present.
- ▼ The test for lipids is physical rather than chemical, depending on the observation of the formation of an emulsion.
- ▼ The biuret test is not a simple test for proteins but is used as such by Biologists
- ▼ These tests are commonly referred to as 'Food' tests as traditionally they are used on samples of food.

## Student Activity

## Materials

- Biochemical test materials
- Safety equipment
- Practical Work Sheet 3:  
**Tests for substances of biological importance**

## Procedure

Follow the detailed instructions on the Practical Work Sheet.

### Set work

Write up and tabulate the results of all your tests.  
Comment on any observations that you recorded  
that are outside of the normally expected results.

Notes:

## 1.2

### Biological Molecules

Learning Outcomes: (b) (c) (d)

**Structure of alpha and beta glucose, formation and breakage of a glycosidic bond. Structure of starch, glycogen and cellulose**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Simple formula for glucose -  $C_6H_{12}O_6$
- ▼ Exists as straight chains in dry powder form.
- ▼ Forms ring structures in solution.
- ▼ alpha and beta glucose are isomers differing in the 3D arrangement of their atoms.
- ▼ Monosaccharides (glucose, fructose and galactose) combine together with the elimination of water to form glycosidic bonds - a condensation reaction.
- ▼ Glycosidic bonds are broken by the addition of the elements of water across the bond - a hydrolysis reaction.
- ▼ Starch is a mixture of amylose (unbranched chains) and amylopectin (branched chains).
- ▼ Amylose and amylopectin both being long chains (polymers) of alpha glucose molecules.
- ▼ When combined the alpha glucose molecules have their oxygen bridges on the same side of the chain, hydrogen bonds form between them and cause the chain to coil into a helix.
- ▼ Starch molecules are relatively insoluble in water.
- ▼ Cellulose is a polymer of beta glucose which have their oxygen bridges on alternate sides of the chain and so cannot form a helix.
- ▼ Instead they form hydrogen bonds with other adjacent chains to make flat ribbons, which form fibres.
- ▼ The differences in structure and properties between starch (digestible powder) and cellulose (structural fibre) are explicable in terms of their molecular structure,

### Student Activity

#### Materials

- Molecular model of alpha and beta glucose.
- Small tasting samples of glucose, fructose, sucrose in powdered form on sterile filter papers
- OHT Monosaccharides and disaccharides
- OHT Polysaccharides

#### Procedure

- OHTs recap structure of carbohydrates.

Construct or observe molecular models of glucose.

'Blind' tasting of fructose, glucose and sucrose.

Put the substances in order of sweetness. Discuss how properties can vary with small molecular differences. (Caution - do not use galactose. Some people are intolerant)

#### Set Work

Make simple molecular diagrams to show the structure of alpha and beta glucose.

Notes: \_\_\_\_\_

## 1.2

### Biological Molecules

#### Learning Outcomes

#### Structure of triglycerides and phospholipids related to their functions in living organisms

### Topic Guide

Session:

#### Check List

- ▼ Triglycerides are composed of three (tri) fatty acids combined by condensation reactions to form ester bonds with glycerol.
- ▼ Fatty acids have long hydrocarbon chains and a carboxyl group (COOH).
- ▼ Saturated fatty acids (and hence saturated fats) have no double bonds in the hydrocarbon chain which is 'saturated' with hydrogen.
- ▼ Monounsaturated fatty acids have one double bond.
- ▼ Polyunsaturated fatty acids have two or more double bonds.
- ▼ Lipids include fats, oils, waxes, phospholipids and steroids.
- ▼ Fats (triglycerides) are energy rich storage products in plants and animals.
- ▼ Phospholipids are formed from triglycerides by the replacement of one fatty acid by a phosphate group.
- ▼ Phospholipids form the structural basis of biological membranes by forming a bilayer.
- ▼ The bilayer is formed with their hydrophobic poles faced into each other, and their hydrophilic poles facing outwards in contact with the aqueous phase.

### Student Activity

#### Materials

- Range of fats, oils and waxes
- OHT Structure of triglyceride
- OHT Phospholipids and the bilayer

#### Procedure

Observe the range of fats, oils and waxes.

Tabulate the location and functions of fats, oils, waxes, phospholipids, cholesterol and steroids in living organisms.

#### Set work

List common foods that contain one of the following:  
saturated fats;  
monounsaturated fats;  
polyunsaturated fats.

Notes:

## 1.2

### Biological Molecules

Learning Outcomes: (1) (1)(1)(1)

#### Structure of amino acids and proteins

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ All amino acids share a common structure consisting of a hydrogen atom, an amino group ( $\text{NH}_2$ ), a carboxyl acid group ( $\text{COOH}$ ), and an 'R' group, all attached to a carbon atom.
- ▼ The 'R' group can range from a single hydrogen atom to a long complex chain. Thus the simplest amino acid has the formula of  $\text{CH}_2\text{NH}_2\text{COOH}$ .
- ▼ Amino acids combine by condensation reactions which form peptide bonds.
- ▼ There are about 20 different types of amino acids found in proteins of living organisms.
- ▼ Proteins are polymers of up to 2000 amino acids joined by peptide bonds (polypeptides)
- ▼ The combination of the 20 different types of amino acids gives rise to as many as 100 000 different types of proteins in living organisms
- ▼ The sequence of amino acids in the polypeptide chain determines the primary structure of proteins.
- ▼ Hydrogen bonds between adjacent  $\text{NH}_2$  and  $\text{COOH}$  groups result in the secondary structure of either alpha helix or beta sheet. Both of these structures may occur in the same protein.
- ▼ Bonds that form between the 'R' groups determine the tertiary structure.
- ▼ Combination or association of two or more polypeptide chains determines the quaternary structure of a protein.
- ▼ Haemoglobin has a quaternary structure involving four polypeptide chains and four iron containing haem groups.

### Student Activity

#### Materials

- Molecular models of two amino acids, one with an 'R' group of just one hydrogen atom, and one with a long chain.
- Popper beads.
- ☐ OHT Amino acid structure and peptide bond
- ☐ OHT Secondary and tertiary structures of proteins
- ☐ OHT Structure of haemoglobin

#### Procedure

Observe 3D models of amino acids

Construct a peptide bond between two amino acids.

#### Set work

In what ways are the structure of Aspartame, insulin, collagen and haemoglobin similar.

In what ways are they different.

Explain why egg albumen changes from liquid to solid (egg white) when cooked.

Notes: \_\_\_\_\_

## 1.2

### Biological Molecules

#### Learning Outcomes - (1) (1)

**Role of water in living organisms, and as an environment for organisms.**

**Inorganic ions.**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Water molecules are dipolar with an electronegative pole and an electropositive pole.
- ▼ The dipolar nature of water causes molecules to be attracted to each other by hydrogen bonds resulting in most of the key properties of water in relation to living organisms.
- ▼ Liquid at normal temperature and pressures, solid (ice) at 0°C, boiling point 100°C, providing a wide range as a liquid.
- ▼ High cohesion resulting in a strong surface film allowing small organisms to be supported on top or underneath it, and the ability for water columns to maintain their continuity without breaking.
- ▼ 'Universal' solvent in which many substances dissolve.
- ▼ Density supports aquatic organisms, ice is less dense than water, therefore ice floats and organisms can survive beneath it.
- ▼ Low viscosity allows free flow for transport of materials inside and outside of organisms.
- ▼ Water rises in small bore tubes by capillarity e.g. important in water transport in plants.
- ▼ Being incompressible water provides a hydrostatic skeleton, e.g. earthworm body cavity, human abdominal cavity
- ▼ Latent heat of evaporation results in a cooling process eg sweating
- ▼ Water has a high specific heat which is important in temperature control of aquatic environments and internal fluids.
- ▼ Transparency allows the transmission of light e.g. for photosynthesis.

### Student Activity

#### Materials

- 2 thermometers with small piece of blotting paper and 2 rubber bands
- Slice of cucumber (5mm wide) + beaker of water
- Small square of cellophane (2-3cm) + beaker of water
- Pieces of capillary tubing (6-10 cm), and tubing of wider diameter + beaker of water
- Collection of 5p coins

#### Procedure

Put cucumber slice into water and see how many 5p coins it takes to sink it

Put cellophane on top of water and see how many coins it takes to sink.

Support tubes upright in water and measure how far the water meniscus rises

Attach small piece of blotting paper to the sensitive end of each thermometer with elastic bands, having

first wetted one of the pieces of blotting paper. Blow on the paper and compare temperatures.

Report on how particular water property (buoyancy, surface tension, capillarity, latent heat of vapourisation) might be of use to living organisms.

#### Set work

Suggest improvements of the investigations that you carried out.

Notes: \_\_\_\_\_

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## 1.3

### Enzymes

Learning Outcomes – (a) (b)

**Enzymes as globular proteins which catalyse metabolic reactions. Enzyme action in terms of an active site, enzyme/substrate complex, lowering of activation energy and enzyme specificity**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ All enzymes are protein in nature, and are 'globular' proteins with a complex 3D structure, as opposed to 'fibrous' proteins.
- ▼ Enzymes are catalysts which speed up the rate of reaction of much larger amounts of reactants without themselves being used up in the process.
- ▼ Unique amongst catalysts they are denatured by extreme conditions of pH and temperature.
- ▼ Their activity depends upon their complex 3D shape which creates an active site which combines with the substrate to form an enzyme/substrate complex which lowers the activation energy of reactants.
- ▼ Their complex 3D shape also accounts for enzyme specificity as the active site has a shape complementary to the shape of the substrate.
- ▼ Disruption of the 3D shape prevents the formation of enzyme/substrate complexes and explains denaturation.

### Student Activity

Notes:

#### Materials



- ☐ OHT Activation energy
- ☐ OHT Enzyme - substrate complex

#### Procedure

- ☐ OHT Activation energy - discussion of activation energy and catalysts.

Use the opportunity to revise tertiary structure, stress the importance of shape.

- ☐ OHT Enzyme-substrate complex to illustrate active site, enzyme-substrate complex, specificity. Define these terms and make notes.

#### Set work

Try to find an example of a non-enzyme catalyst, the reaction it catalyses, and the conditions necessary for the reaction to proceed.



## 1.3

### Enzymes

#### Learning Objectives (LOs)

**The effects of pH, temperature, enzyme and substrate concentration on enzyme action. Rates of formation of end products or rate of disappearance of substrate in following the time course of enzyme catalysed reactions.**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ pH has an effect on the 3D shape of enzymes and particularly the active site which has an electric charge.
- ▼ Any effect on the active site alters the reactivity of the enzyme. There is an optimum pH either side of which reactivity drops.
- ▼ Extremes of pH permanently disrupt the active site and thus denature the enzyme.
- ▼ Similar effects are seen with temperature, except low temperatures do not denature enzymes. The rate of enzyme catalysed reactions, like all chemical reactions, are reduced with low temperatures.
- ▼ Optimum conditions of pH and temperature vary with the particular enzyme, which reflects the conditions in which the cell exists.
- ▼ The relative amount of enzyme and substrate affect the rate of reaction as it affects the formation of the enzyme substrate complex. Only one can be rate regulating (limiting) at any one time.
- ▼ Rates of disappearance of substrate are proportional to the rate of reaction.
- ▼ Rates of formation of end-product(s) are proportional to the rate of reaction.

## Student Activity

Notes: \_\_\_\_\_

### Materials

- Practical Work Sheet 4:  
**Following the time-course of an enzyme-catalysed reaction by measuring the rate of formation of products using catalase.**
- Practical Work Sheet 5:  
**Following the time-course of an enzyme-catalysed reaction by measuring the rate of disappearance of substrate using amylase**
- OHT Effects of temperature, pH, enzyme and substrate concentration on enzyme activity.

### Procedure

Follow the procedures on the Practical Work Sheets.

### Set work

Plot the curve for the rate of a typical chemical reaction against temperature from 0 - 100°C

On the same axes plot the rate of an enzyme catalysed reaction with an optimum temperature of 40°C.

Explain the relationship shown by the two curves.

## Enzymes

## Leonine Entrance (cf)

## Topic Guide

Session:

- ▼ Irreversible enzyme inhibitors are also referred to as poisons or toxins.
- ▼ Reversible inhibitors, in contrast, are not permanently damaging to enzymes, but typically act as regulators in cell metabolism.
- ▼ Competitive inhibitors have a molecular structure resembling that of the normal substrate to which the enzyme binds, and compete for the active site.
- ▼ The more molecules of competitive inhibitor there

▼ Non-competitive inhibitors bind to the enzyme at a site away from the active site at a location known as the allosteric site.

▼ Combination at the allosteric site results in a change of shape of the enzyme molecule and active site, preventing the formation of enzyme-substrate complexes.

Notes:

□ OHT Graphs of reversible enzyme inhibition (competitive and non competitive)

Copy the graphs from □ OHT Graphs of reversible enzyme inhibition (competitive and non competitive) and annotate to explain the differences in the shapes of the curves.

Draw a theoretical illustration of two similarly shaped molecules competing for an active site of an enzyme (remember that usually the protein enzyme molecule is larger than the substrate molecule(s)).

## 1.4

### Cell membranes and Transport

Examining Outcomes - (4)

**Describe and explain the fluid mosaic model of membrane structure**

#### Topic Guide

Session: \_\_\_\_\_

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#### Check List

- ▼ All cell membranes are thought to share the same structure except the inner membrane of mitochondria.
- ▼ This is based on a lipid bilayer formed from phospholipids aligning themselves with their hydrophobic poles next to each other within the membrane, and hydrophilic poles facing outwards.
- ▼ This fluid arrangement is stabilised by the presence of another lipid - cholesterol.
- ▼ Various proteins are embedded within this lipid bilayer.
- ▼ Extrinsic proteins are found on the surface of the membrane.
- ▼ Intrinsic proteins have one end embedded in the lipid bilayer and the other protruding out of the external surface of the membrane.
- ▼ Transmembrane proteins span the lipid bilayer and create aqueous channels (pores) through which water soluble substances can pass by diffusion.
- ▼ Short polysaccharide chains attached to proteins (glycoproteins) and to fats (glycolipids) protrude from the external surface and act as cell recognition sites (receptors or antigens).
- ▼ The patchwork arrangement of all these types of molecules in the lipid bilayer is the origin of the description 'mosaic'.

### Student Activity

#### Materials

- ☐ OHT Phospholipids and the bilayer
- ☐ OHT The fluid mosaic model

#### Procedure

- ☐ OHT Phospholipids and the bilayer explains the structure of cell membranes, building up the fluid mosaic model from the phospholipid bilayer.

The OHT can be used as a back transparency for drawing in first cholesterol (slows down lateral movement of phospholipids and also makes the membrane less permeable), then the three types of protein, extrinsic, intrinsic, transmembrane, and glycoproteins and glycolipids.

- ☐ OHT summarises the final structure.

Place some well washed identical slices of beetroot (washed until no more pigment is released) in beakers of water at a range of temperatures from 0°C to 100°C; and in a range of dilutions of detergent, and observe the release of pigment from the slices. Use a colorimeter if available.

#### Set work

List all the structures in plant, animal and bacterial cells which include membranes in their structure.

Tabulate the results from the experiment with beetroot slices, and comment on the results.

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## 1.4

### Cell membranes and Transport

Learning Objectives (b) (c)

**Roles of membranes within and at the surface of cells. The processes of passive diffusion, osmosis, facilitated diffusion, active transport, endocytosis and exocytosis.**

### Topic Guide

Session:

#### Check List

- ▼ The cell surface membrane defines the limits of the cell.
- ▼ It receives 'messages' by providing receptor sites for hormones, cell recognition of 'self' and 'non-self' substances and structures (acting as antigens).
- ▼ It acts as a partially permeable membrane regulating the transport of substances across the membrane.
- ▼ Internal membrane systems provide a surface for attachment of organelles and enzymes, and compartmentalise specialised functions within the cell.
- ▼ Passive diffusion occurs across membranes down diffusion gradients from high concentration to low concentration. Fat soluble substances diffuse faster than non-fat soluble substances which must pass through the aqueous pores.
- ▼ Osmosis is the special case of the diffusion of water from regions of higher water potential to regions of

lower water potential across a partially permeable membrane which is more permeable to water than to dissolved solutes. (If the membrane was fully permeable the solutes would diffuse down their diffusion gradient and the water would not move.

- ▼ At room temperature and pressure pure water has the highest water potential which is given the value of zero. Solutions have a water potential of less than zero (negative).
- ▼ Negative figures are 'reversed' in magnitude, e.g. -1 is a greater value than -10.
- ▼ Facilitated diffusion occurs via specialised carriers in the membranes which reduce the resistance to the diffusion of these substances.
- ▼ Active transport involves energy in the form of ATP from respiration to pump ions across the cell surface membrane via carriers against their diffusion gradient.
- ▼ Mass or bulk transport of fluids into and out of the cell is achieved by vacuoles fusing with, or being pinched off from, the cell surface membrane.

### Student Activity

#### Materials

- Beakers, measuring cylinders etc.
- Range of plant material
- Methylene blue

#### Procedure

Investigate the water potential of a range of plant material: potato chips, beetroot (which allows for a check on any losses from damaged cells), onion rings, banana slices of different ripeness.

An alternative approach is to investigate any alterations of density of bathing solution by colouring with methylene blue and releasing a drop of this carefully at mid-depth into a beaker of the original solution, if water has entered the cells by osmosis the bathing solution will have become more concentrated, and will sink when introduced into original solution. If the bathing solution has gained

water from the cells it will be less dense than the original and rise when introduced into the original.

Osmosis and diffusion can be studied in the same investigation if solutions of urea are used. Initially plant material loses water to a concentrated urea solution and shrinks and loses mass, but after a period urea diffuses into the plant material which recovers size and mass. A puzzling and interesting phenomenon to observe.

#### Set work

Draw up observations from these investigations.

Notes:

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## 1.4

### Cell membranes and Transport

Learning Outcome: (d) (12)

**The features of the gaseous exchange surface of the mammalian lung.**

**The features of root hairs.**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ The gaseous exchange surface of the mammalian lung is the squamous epithelium lining the alveoli of the lungs.
- ▼ Squamous epithelium is made up of tightly interlocking thin flattened cells with a large surface area to volume ratio.
- ▼ The total surface area of the lungs is large as a result of being divided up into millions of alveoli.
- ▼ Dense capillary networks sandwiched between the walls of the alveoli make their surfaces ridged thus further increasing their surface area.
- ▼ A film of water covers the surface as an inevitable consequence of having one side of a permeable surface exposed to air.
- ▼ Root hairs consist of one cell with an elongated 'hair-like' protrusion, giving each one a large surface area to volume ratio.
- ▼ Large numbers of root hair cells just behind the growing tips of roots present a large total surface area for the uptake of water and solutes from the soil solution.
- ▼ Carrier molecules in their membranes enable the active uptake of ions (especially positively charged cations) from the soil solution.
- ▼ Cations are held by the electronegative clay particles of the soil, and are liberated by exchange with hydrogen ions from the cellular respiration of the root hair cells.

### Student Activity

#### Materials

- Microscopes
- Slides of TS alveoli
- Slides of root hairs
- Seedlings grown in soil-free medium in petri dishes showing root hairs
- ☐ OHT Diffusion at alveolus
- ☐ OHT Cation exchange by root hairs.

#### Procedure

☐ OHT Diffusion at alveolus. Apply Fick's law to the rate of diffusion of oxygen from the alveolar air to the blood given that a pair of adult human lungs have an alveolar surface of approximately  $120\text{m}^2$  and that the diffusion distance is about  $2.5\text{ }\mu\text{m}$ . (All these figures are estimates and can vary widely). What else needs to be known in order to make a calculation? What effect would doubling the diffusion distance have?

Observe the slides of the alveoli and root hairs, and make drawings.

Observe living root hairs on seedling.

#### Set work

List the similarities and differences between alveoli and root hairs as specialised exchange surfaces.

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## Genetic Control of Protein Structure and Function

## Library of Congress - LCCN 91-011111

## The structure of DNA and RNA

## DNA replication

## Topic Guide

Session:

### Check List

- ▼ DNA and RNA are long chain polynucleotide molecules with repeating sub-units of nucleotides.
- ▼ Nucleotides consist of a 5 carbon sugar, a phosphate, and a nitrogen containing organic base.
- ▼ In DNA the sugar is deoxyribose and the organic base can be one of adenine, thymine, cytosine or guanine.
- ▼ In RNA the sugar is ribose and the organic base can be one of adenine, uracil, cytosine and guanine.
- ▼ The DNA molecule is a double stranded helix with the two strands held together by hydrogen bonds between complementary base pairs adenine-thymine and cytosine-guanine.
- ▼ RNA is a single stranded helix with base pairs of adenine-uracil and cytosine-guanine.
- ▼ There are three types of RNA - messenger, transfer and ribosomal.
- ▼ DNA carries out semi-conservative replication in which each strand of the original molecule acts as a template for the construction of a new one, so that each new double stranded molecule of DNA consists of one original strand and a new complementary one.

## Student Activity

## Materials

- DNA molecular model
- OHTs showing structure of DNA, RNA and semi-conservative replication (with DNA polymerase)

## Procedure

Use the 3D model of DNA structure to clarify any problems with envisaging the 3D structure from 2D diagrams.

### Set work

What does 'semi-conservative replication' mean? Explain a piece of experimental evidence for semi-conservative replication.

Notes:

## 1.5

### Genetic Control of Protein Structure and Function

Learning Outcomes – (L1) (H)

#### Genetic code

#### Topic Guide

Session: \_\_\_\_\_

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#### Check List

- ▼ The sequence of bases (and hence nucleotides) on one strand of the DNA molecule carries the genetic code for the synthesis of proteins and hence ultimately living cells.
- ▼ Three bases (a triplet codon) code for one amino acid.
- ▼ There are 64 possible combinations of any three from four bases, but only 20 amino acids to be coded for.
- ▼ Amino acids are coded for by more than one triplet codon and the code is said to be 'redundant' or 'degenerate'.
- ▼ A gene is a sequence of nucleotides (bases) of a DNA molecule which codes for a polypeptide.
- ▼ A gene for a polypeptide has a specific 'start' codon which thus sets the order of all the subsequent triplet codons
- ▼ Thus the code is non-overlapping i.e. a base can only be 'used' in one triplet codon.
- ▼ Only a fraction of the nuclear DNA contains genes coding for proteins, the rest consists of so-called 'junk' DNA the function of which is not understood

#### Student Activity

Notes: \_\_\_\_\_

##### Materials

- ☐ OHT showing base sequence / gene code
- ☐ OHT showing codons for amino acids

##### Procedure

Use OHTs to revise and discuss the genetic code

##### Set work

Draw out a random sequence of bases of a strand of DNA and annotate it to demonstrate the non-overlapping nature of the genetic code.

Draw out the complementary strand of DNA to the one that you have drawn and annotate to illustrate how only one strand can carry the genetic information.

## Genetic Control of Protein Structure and Function

## Learning Outcomes – (1) (1)

## Transcription and translation of the genetic message

## Topic Guide

Session:

### Check List

- ▼ Nuclear DNA with the genetic code never leaves the nucleus in eukaryotic cells.
- ▼ The genetic code for a polypeptide (a gene) is copied (transcribed) into mRNA which leaves the nucleus and associates with the ribosomes.
- ▼ The ribosomes 'read' the genetic message on the mRNA and tRNAs deliver amino acids in the sequence determined by the code.
- ▼ There are 20 different types of tRNA, each specific to a particular amino acid.
- ▼ Each tRNA has a specific binding site at which the specific amino acid combines and an anti-codon which matches the specific codon for that particular amino acid.
- ▼ The amino acids combine by means of peptide bonds to give a polypeptide chain.
- ▼ The polypeptides subsequently form proteins.
- ▼ As enzymes are proteins their synthesis is controlled by DNA.

## Student Activity

## Materials

- OHT Transcription and translation

## Procedure

- OHT Transcription and translation

Can be used to revise transcription and translation.

Consider the 'universality' of the genetic code and the mechanisms of transcription and translation.

Consider the transferability of mRNA and tRNA between species, e.g. if human mRNA was transferred into a bacterium what would be the outcome. Similarly for tRNAs.

## Set work

DNA replication, translation, and RNA transcription all require enzymes to catalyse their reactions. Explain the particular problem that this represents in terms of protein synthesis.

Notes:



## Genetic Control of Protein Structure and Function

### Learning Outcomes – (10)

## General principles of gene manipulation by biotechnology

## Topic Guide

Session:

## Check List

- ▼ Isolation of the gene to be manipulated is the first step
- ▼ It is easier to find and isolate the appropriate mRNA which has been transcribed (copied) from the relevant DNA, than it is to try and isolate the particular length of DNA itself.
- ▼ The enzyme reverse transcriptase can then be used to make a copy of the DNA from the mRNA.
- ▼ Plasmids (circular DNA) are isolated from bacteria.
- ▼ Plasmids are cut open by restriction enzymes and the length of DNA is inserted and the plasmid resealed by ligase enzymes.
- ▼ The genetically modified plasmids are then reintroduced into the bacteria.
- ▼ The bacteria multiply and produce the protein coded for by the inserted DNA.
- ▼ To identify those bacteria which have successfully taken up the modified plasmids marker genes are incorporated along with the required gene.
- ▼ Marker genes include those for antibiotic resistance so that the culture can be flooded with antibiotic and only the bacteria with the marker gene will survive.
- ▼ Two early successes with these techniques were the synthesis of human insulin for the treatment of diabetics, and blood clotting factor VIII for the treatment of haemophiliacs.

## Student Activity

## Materials

- ☐
- OHT Genetic engineering

## Procedure

OHT Genetic engineering illustrates the actions of the three enzymes (reverse transcriptase, restriction endonuclease and DNA ligase) which are the basic tools of genetic engineering, and the main steps involved.

### Set work

Define the following terms: 'recombinant DNA', 'genome', 'plasmid', 'bacteriophage', 'vector'.

Notes:

## 1.6

### Nuclear Division

Learning Outcomes: (a) (b) (c) (d)

#### Mitosis: occurrence and significance including cancer

### Topic Guide

Session:

#### Check List

- ▼ Mitosis is nuclear division in which the daughter nuclei have the same chromosome number as the parent nucleus, typically diploid nuclei producing diploid daughter nuclei.
- ▼ The daughter nuclei are therefore genetically identical to the nucleus of the cell that produced them (except for any mutations that may occur).
- ▼ Mitotic cell division is seen in growth, repair and asexual reproduction.
- ▼ As a result of mitosis in the growth of an organism from the fertilised egg all cells therefore are genetically identical.
- ▼ Similarly, offspring of asexual reproduction lack genetic variation.
- ▼ The production of genetically identical cells retains the full set of genetic information needed for the replacement of any cells in repair processes, and in the asexual reproduction of organisms it allows for the rapid exploitation of optimum conditions where any variation would be disadvantageous.
- ▼ Cancer is the result of uncontrolled mitotic cell division.
- ▼ Any factor that disrupts normal control of mitosis increases the chances of cancerous growth e.g. ultra-violet light, X-rays, and carcinogenic chemicals.
- ▼ The DNA replicates in interphase so that in the first stage of mitosis (prophase) the chromosomes appear as double structures of two chromatids (daughter chromosomes) joined at the centromere.
- ▼ The nuclear spindle apparatus (NSA) forms from the dissolution of the nuclear membrane and the centrioles replicate and migrate to either pole of the NSA.
- ▼ The centromeres align on the equator of the NSA (metaphase).
- ▼ The centromeres divide and the chromatids are moved to the opposite poles (anaphase).
- ▼ Two new daughter nuclei are formed (telophase).

### Student Activity

#### Materials

- Microscopes
- Slides of root tip squashes
- Student handouts: photocopies of OHT
- **Supplementary Practical Sheet 6: Preparation of an onion root tip squash to observe stages in mitosis**

- ☐ OHT Root tip squash
- ☐ OHT Normal Human Karyotype (A) (B)

#### Procedure

Observe slides of root tip squashes.

Use ☐ OHT Root tip squash for guidance.

Make drawings of prophase, metaphase, anaphase and telophase stages. Look for similarities between the root tip cells and the human nucleus.

Carry out the root squash procedure using the Practical worksheets.

#### Set work

Determine at what stage in mitosis the photograph of the human nucleus and chromosomes was taken, and from what type of cell. Explain your reasons.

Notes:

## Nuclear Division

**Learning Outcomes:** (a) 15

### Homologous pairs of chromosomes and the need for a reduction division prior to fertilisation in sexual reproduction

## Topic Guide

Session:

## Check List

- ▼ Each gamete of a sexually reproducing organism contains one set of chromosomes (haploid). (homozygous) or a pair that differs slightly (heterozygous).
- ▼ When two such gametes fuse in fertilisation they produce a zygote with two sets of chromosomes (diploid).
- ▼ Pairs of sex determining chromosomes are only partially homologous e.g. the human Y chromosome has a short non-homologous arm which carries the male determining genes.
- ▼ Chromosomes in a diploid nucleus thus occur in pairs, each member of a pair carrying the same genes in the same relative positions (homologous chromosomes).
- ▼ The production of haploid gametes from a diploid cell requires a reduction division (meiosis) in which the chromosome number is halved from diploid to haploid.
- ▼ Slight variations (alleles) of a gene at a particular locus can arise by mutation, so that an organism can either have an identical pair of genes at a locus
- ▼ The production of haploid gametes ensures the maintenance of the diploid chromosome number in subsequent generations.

## Student Activity

## Materials

- Handout of Human Karyotype analysed into homologous pairs
- OHT Human Karyotype analysed into homologous pairs

## Procedure

Examine the pairs of homologous chromosomes of the Human Karyotype. Note that before the development of staining techniques that revealed differences in dark staining bands, it was not possible to pair up the chromosomes into homologous pairs with any confidence.

### Set work

Explain why chromosome studies are carried out on squashes of cells and not sections.

Notes:

Continuing Education (6)

Session:

▼ Migration amongst animals further blurs the boundaries of many of these arbitrary divisions.

Notes:

- Photocopy of a map of an appropriate area of ecological interest

Consider the 3 component parts of an ecosystem, climatic, biotic and edaphic and suggest ways in which the 3 components interact.

Use the map to try to rationalise some of the divisions and overlaps between these definitions.

Draw an imaginary enlargement of an area to demonstrate a habitat. Consider how this relates to plants.

Write one sentence each to explain the following terms used in ecology: habitat, niche, population, community, and ecosystem.

Try to think of an example which does not fit these categories.

## 1.7

### Energy and Ecosystems

Learning Outcomes: 1b, 1c, 1d

**Producer, consumer, food chains, food webs, trophic levels, and the efficiency of energy transfer**

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Producers 'produce' the organic matter on which all life depends. Virtually all producers are photosynthetic, converting light energy from the sun into the stable chemical energy of organic compounds.
- ▼ Consumers 'consume' producers and each other to obtain a supply of ready-made organic material.
- ▼ Feeding relationships can be considered as food chains and webs with organisms at different feeding or trophic levels, although organisms can feed at more than one level.
- ▼ The efficiency of energy transfer between trophic levels is typically less than 10% due to losses in conversion.
- ▼ Photosynthetic producers only trap a small fraction of the available energy of sunlight, inefficiencies of digestion and absorption mean that most organic matter is not assimilated by consumers.
- ▼ Energy losses as heat as a result of the inefficiencies of cell respiration also occur.
- ▼ The resulting loss of energy 'up' a food chain allows organisms at different trophic levels to be represented in pyramids of biomass or energy.
- ▼ Typically there is a maximum of four trophic levels in a food chain as a result of these losses at each level.

### Student Activity

#### Materials

- Set of Pond Life playing cards (provided) for each group of two or three
- Student worksheet
- Graph paper and ruler
- OHT Pyramid of biomass.

#### Procedure

Prepare the sets of playing cards by cutting out the pond invertebrate diagrams.

Consider how the data might have been collected and the meaning of the numbers and symbols on each card.

H = herbivore, C1 = 1st level carnivore, C2 = 2nd level carnivore, D = detritivore (animal which eats dead and decaying matter, or detritus)

Numbers refer to the total caught in the sample. average dry mass is included for each organism.

1 Arrange the cards to make up two or three possible food chains. Now make the chains link up to form a possible food web.

2 Make a table of all the invertebrates under the following headings:

name of invertebrate / feeding type / total in sample / dry mass / biomass

Calculate the biomass by multiplying the dry mass by the total

3 Calculate the total dry mass of herbivores, primary carnivores, secondary carnivores and detritivores.

4 Use the graph paper to construct a pyramid of biomass to scale.

5 In what way(s) does your pyramid of biomass differ from the one illustrated here. Note that it does not appear as expected (OHT). There are many more detritivores and fewer herbivores. Suggest reasons for any differences.

#### Set work

What time of year was the survey carried out?

How does detritus get into the pond?

In what ways would you expect the sample to be different in April? In January?

Suggest why the pyramid looks like it does. Bear in mind the time of year that the sample was collected (mid June), and the fact that a pond receives a large quantity of imported dead matter from the surrounding vegetation (leaves, fruits etc).

In what ways would you expect the sample to be different in April and January?

## Energy and Ecosystems

## The nitrogen cycle

## Topic Guide

Session:

## Check List

- ▼ The principle conversions in the nitrogen cycle are between the three reservoirs of nitrogen and its compounds: the atmosphere, soil and water, and living organisms.
- ▼ Nitrogen fixing microorganisms, e.g. Rhizobium bacteria can convert nitrogen to nitrogen containing organic compounds such as amino acids which are the building blocks of proteins.
- ▼ Rhizobium forms a mutualistic association in the root nodules of certain plants (Papilionaceae).
- ▼ Dead organic matter decomposes and releases nitrogen containing compounds, e.g. ammonia. and ammonium compounds.
- ▼ Chemosynthetic nitrifying bacteria *Nitrosomonas* and *Nitrobacter* use these as a source of energy for their synthetic processes, and result in the production of nitrate ions.
- ▼ Plants take up ammonium and nitrate ions and combine them into amino acids and proteins, and other nitrogen containing compounds, e.g. ATP and DNA.
- ▼ Animals consume plants and each other and these nitrogen containing compounds form an essential part of the diets of consumers.
- ▼ Animals die and decompose and the cycle continues.
- ▼ Anaerobic denitrifying bacteria convert nitrates back to nitrogen.
- ▼ Man now has a considerable effect on the Nitrogen cycle by the use of artificially produced nitrate fertilisers.

## Student Activity

## Materials

- Leguminous plant with washed roots showing root nodules.
  - Soil testing kit.
  - Sample of soils
  - Filter paper, funnels and beakers
- OHT Nitrogen cycle

## Procedure

Make a sketch of the root system of the plant provided.

Test a sample of soils for nitrogen content.

Place samples of the soils on filter papers in funnels and pour distilled water through them. Test the filtrate for nitrogen content

### Set work

Write up the results of your soil test investigation.

Notes:

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# Topic Guides



- 2.1 Introduction to Health and Disease**
- 2.2 Diet**
- 2.3 Gaseous Exchange and Exercise**
- 2.4 Smoking and Disease**
- 2.5 Infectious Diseases**
- 2.6 Immunity**

## 2.1

### Introduction to health and disease

Learning Outcome (LO)

**The terms health and disease. The concept that health is more than the absence of disease.**

### Topic Guide

Session:

### Check List

- ▼ The terms health and disease are commonly used but poorly understood and impossible to measure. They are also subjective.
- ▼ The WHO suggests a definition of health which includes physical, mental and social components.
- ▼ Health is not simply the opposite of having a definable disease.
- ▼ A disease disrupts the normal functioning of the body. This could include mental and/or physical functioning.
- ▼ Diseases all have specific signs and symptoms which allow them to be diagnosed.

### Student Activity

Notes:

#### Materials

- Blank OHT sheets and pens/white board
- OHT sheet with WHO definition of health

#### Procedure

Discuss the key points to try and emphasise that the concept of health and disease are highly subjective.

Questions such as 'what does being in good health/being healthy mean' and 'what is a disease' could be used.

Show WHO definition for comparison.

In view of the WHO definition discuss the following cases and say whether they would consider each individual to be healthy or diseased.

- a) A woman with depression
- b) An anorexic teenage girl
- c) A man with lung cancer
- d) A girl with a broken arm.
- e) A boy with chicken pox
- f An obese man.

#### Set Work

Write a paragraph on ageing past one's prime as a degenerative disease.



### Categories of disease

## 31

## Introduction to health and disease

## Reasons for collecting health statistics

## Topic Guide

Session:

## Check List

- ▼ The collection and study of disease/health statistics is known as epidemiology.
- ▼ Health statistics are essential to disease treatment and prevention programmes.
- ▼ Basic health statistics used to assess the overall health of a population include life expectancy and infant mortality rate.
- ▼ The number of cases of morbidity and mortality for individual diseases are also collected.
- ▼ Data can be used to establish associations between certain diseases and risk factors: e.g. between smoking and lung cancer. This may lead to research into the causes of the disease.
- ▼ Generally very large amounts of statistical data must be collected, in carefully defined studies and analysed using appropriate tests.
- ▼ Epidemiologists gathering data on a disease may consider the effects of factors such as age, sex, socio-economic group, occupation, geographical location of the disease.

## Student Activity

## Procedure

The main objective here is to introduce the concept of health statistics as a background to later parts in this module.

Emphasis should be on the collection of large amounts of data, often over prolonged periods (longitudinal studies), e.g. Doll's study of smoking and disease.

The use of statistical tests as a means of analysing and 'making sense' of data should be discussed, as well as the concept of the 'fair test': ensuring that only one factor is studied at a time.

## Set Work

Toss a coin as many times as is reasonable and record the heads and tails.

Notes:

## 2.1

### Introduction to health and disease

LEARNING OBJECTIVES (LOs)

#### Standards of health in developed and developing countries

#### Topic Guide

Session:

#### Check List

- ▼ Biological, social, economic and political factors influence the pattern of diseases found across the world.
- ▼ Using life expectancy and infant mortality rate as indicators, the developed world has, on average, a better overall standard of health than the developing world. Ideally the quality of life also needs to be considered, although it is hard to measure.
- ▼ Developed countries show long life expectancy and low infant mortality. Degenerative diseases account for most deaths. Mental diseases are also a major cause of illness.
- ▼ High standards of health have been achieved in the past century due to improved nutrition, education, health services, economic prosperity and political stability.
- ▼ Developing countries have, on average, lower life expectancy and higher infant mortality. Infectious diseases remain the main cause of death in many countries but degenerative diseases are also becoming very common, especially in urban areas.
- ▼ Poor nutrition, lack of basic sanitation, low levels of education, and insufficient medical facilities, low GDP and geographical isolation are factors in low health standards.

### Student Activity

#### Materials

- OHT Patterns of disease

#### Procedure

Discuss the meanings of the terms 'developed' and 'developing' countries with reference to the fact that differences in standards of health can vary enormously within a developed or developing region owing to geographical and socio-economic factors.

In considering the health standards of the developing world emphasis should be placed on the fact that many of the deaths (particularly infant deaths) from infectious diseases are, in theory, easily preventable.

The difficulty of measuring health standards and the idea of quality of life should also be raised.

#### Set Work

If you were asked to assess the standard of health of a region, which factors, other than infant mortality and life expectancy would you take into account.  
Hint: look back to the WHO definition of health

Notes:

## 2.1

### Introduction to health and disease

LEARNING OBJECTIVES

#### Pandemic, Epidemic and Endemic diseases

### Topic Guide

Session:

#### Check List

- ▼ An endemic disease is one which is always present in a region and causes a similar number of illnesses and deaths every year.
- ▼ Epidemics are defined as short term increases in the national incidence of a disease which normally occurs at much lower levels.
- ▼ Pandemics are epidemics which affect most or all of the world at the same time.
- ▼ The same diseases may be endemic, epidemic or pandemic depending on circumstances.

### Student Activity

#### Procedure

The terms endemic, epidemic and pandemic should be defined with reference to examples of each.

Discuss which diseases are endemic in Britain now, and which have been in the past.

#### Set work

Write a paragraph on why pandemics are likely in these modern times, despite increasing control measures against infectious diseases.

Notes:

## Introduction to health and disease

## The significance of the human genome project on health and disease

## Topic Guide

Session:

### Check List

- ▼ The Human Genome Project aims to have an accurate sequence of the entire human genome (genes and non-coding DNA) by the end of 2000. This is a starting point for future genetic research.
- ▼ Comparison of DNA from several individuals has so far indicated that all humans share about 99.9% of the DNA base sequence: the 0.1% difference is of great medical interest.
- ▼ The long term significance of the human genome project is enormous. It should allow for identification of disease genes, associated improvements in genetic screening, gene therapy, the rise of pharmacogenetics and advances in genetic engineering.
- ▼ Such advances should thus improve diagnosis, treatment, prevention and cure of a range of diseases with the potential to improve health standards across the world.

## Student Activity

## Procedure

In introducing the concept of the human genome project it should be emphasised that the primary aim of the Human Genome Project is to produce a DNA sequence.

It is research stemming from this which is significant to health and disease.

The main applications should be discussed, especially the ethical implications of the new technology.

Genetic screening is an interesting topic to discuss: the pros and cons of advances in this for individuals and society could be highlighted.

### Set Work

Use the internet to find out about the latest progress with the human genome project. One site to start at is the Wellcome Trust Web Site: **[www.wellcome.ac.uk](http://www.wellcome.ac.uk)**. Here you can find information about the project itself and about the Sanger Centre where some of the work is taking place. Note down the current state of affairs: how many bases have been sequenced, anticipated completion date, and progress in terms of applications of the data. You will also find information about pharmacogenetics and other genetic technology at this and linked sites.

Notes:

### Diet

## Learning Objectives: (a) (b) (c)

List the components of a balanced diet

## Energy and nutrient requirements of people

### Dietary reference values

## Topic Guide

Session:

## Check List

- ▼ The balanced diet should contain carbohydrates, fats, proteins, vitamins, minerals, water and fibre in the correct proportions.
- ▼ Energy and nutrient requirements vary with gender, age, activity, pregnancy and lactation.
- ▼ Males are generally larger than females and have a greater proportion of muscle, and thus a greater metabolic rate.
- ▼ Metabolic rate and activity fall with age, often resulting in gain in body mass.
- ▼ Activity levels may be expressed as multiples of the Basal Metabolic Rate (the BMR at rest).
- ▼ Energy requirements are expressed as Estimated Average Requirements (EARs) obtained by multiplying the BMR by the average physical activity level of an individual of a particular age group.
- ▼ Dietary Reference Values (DRVs) are based on the range of requirements for each nutrient within a population, which is assumed to be normally distributed.
- ▼ Estimated Average Requirements (EAR) will satisfy the requirements for half the population in a given group.
- ▼ Reference Nutrient Intake (RNI) will satisfy the requirement for protein, minerals, and vitamins for more than 97% of a given population.
- ▼ Lower Reference Nutrient Intake (LRNI) for protein, minerals, and vitamins are sufficient for only 2.5% of a given population.
- ▼ Safe Intakes are estimated where there is not enough information to derive EARs, RNIs, or LNRIs
- ▼ RNIs and LNRIs are not given for energy requirements.

## Student Activity

## Materials

- Collection of food labels and packaging for nutrient information
- OHT Dietary Reference Values curve

## Procedure

- ❑ OHT Dietary Reference Values curve for careful explanation of the above terms.

Study the collection of food labels and packaging and summarise the information provided.

Try to analyse the records of food intake that have been compiled in terms of DRVs.

### Set Work

List the uses of DRVs.

Notes:

## 2.2

### Diet

#### Learning Outcomes - (1)

Functions of essential amino acids, essential fatty acids and vitamins A and D

### Topic Guide

Session: \_\_\_\_\_

### Check List

- ▼ Essential nutrients are those which must be present in the diet for the maintenance of health.
- ▼ 8 amino acids are essential in adults (10 in children), the other 12 (10 in children) amino acids can be synthesised in the liver from the essential amino acids.
- ▼ Proteins containing the essential amino acids are known as 'proteins of high biological value'.
- ▼ There are two essential fatty acids, both of which are polyunsaturated.
- ▼ Vitamin A (retinol) is essential for the visual pigment rhodopsin in the retina, for healthy skin and epithelia, and growth and bone formation in children. Excess can be toxic.
- ▼ Vitamin D or calciferol is found especially in eggs, dairy products, and some oily fish; but is also formed by the action of UV light on the skin. It is essential for strong bones and teeth. Excess can be toxic.

## Student Activity

Notes: \_\_\_\_\_

### Materials

- Food labels and packaging
- OHT RNIs for vitamins.

### Procedure

Examine the collection of food labels and packets for the essential nutrient content.

Analyse the differing needs between individuals with

- OHT RNIs for vitamins.

Discuss the status of vitamin D as a vitamin in view of the fact that it is only needed in the diet under conditions of low exposure of the skin to sunlight.

### Set work

In recent debates about the value of vitamin supplements, some commentators have maintained that the only effect of such supplements is to enrich the local rivers. With regard to the elimination of excess vitamins from the body in the urine, explain why the above observation needs refining.

### Diet

Energy and protein deficiency, anorexia nervosa, vitamin A and D deficiencies, and obesity.

### Links between diet and coronary heart disease.

## Topic Guide

Session:

- ▼ Protein and energy deficiencies frequently occur together as Protein Energy Malnutrition (PEM).
- ▼ PEM is more common in children due to their smaller reserves and higher requirements. PEM in children has consequences for the rest of their lives.
- ▼ Anorexia nervosa is characterised by an obsessive desire to lose weight, and a distorted self-image, and is more common in adolescent girls in developed countries.
- ▼ Anorexia nervosa is a mental (psychological) disorder, involving predisposing biological and social factors.
- ▼ Vitamin A deficiency results in nightblindness, drying of the surface tissues of the eye (xerophthalmia) leading to blindness, and thickening and drying of the skin.

- ▼ Vitamin D deficiency results in poor bone growth and development in the young (rickets). In adults deficiency results in softening of the bones as they lose calcium (osteomalacia).
- ▼ Obesity is defined as being 20% heavier than the average for the particular group; or as having a Body Mass Index (BMI) greater than 30 in men, and 28 in women.
- ▼ Obesity is the major nutritional disorder in the developed world, and carries increased risk of other conditions, e.g. cardiovascular disease, type II diabetes, and cancer..
- ▼ Coronary heart disease is a multi-factorial disease (having many causes) and diet is a major factor.

Notes:

- ☐ OHT Body Mass Index
- ☐ OHT Coronary heart disease risk factors
- ☐ OHT Coronary heart disease risk factors questions

Answer the questions on ☐ OHT Body Mass Index  
Take care not to embarrass members of the group.  
Work through the questions on ☐ OHT Coronary  
heart disease risk factors.

Write a paragraph on the Mediterranean Diet



## Gaseous Exchange and Exercise

**Learning Outcomes:** (a) (b) (c)

## Structure and function of respiratory system

## Topic Guide

Session:

### Check List

- ▼ The lungs have a huge internal surface area as a result of the millions of air sacs (alveoli).
- ▼ The pulmonary arteries supply the lungs from the right atrium, and the pulmonary veins return oxygenated blood to the left atrium of the heart.
- ▼ The pulmonary capillary beds supplying the alveoli are amongst the most dense in the body.
- ▼ The lungs are organs composed of several specialised tissues.
- ▼ Cartilage supports the larger airways preventing collapse when the internal pressure of the thorax is reduced.
- ▼ Goblet cells secrete mucus which traps inhaled particles, and ciliated epithelium sweeps it up the trachea to be removed by the cough reflex.
- ▼ Smooth muscle fibres can alter the diameter of the airways by their contraction and relaxation.
- ▼ Elastic fibres enable the lung tissues to accommodate the changes in volume involved in breathing-in and out, and enable breathing-out to be passive by elastic recoil of the stretched tissues.

## Student Activity

## Materials

- Microscopes
- Prepared slides of TS lung tissue, T.S Trachea

## Procedure

Observe the trachea and ciliated epithelium, and the alveoli and capillaries on the prepared slides.

Make annotated sketches of each one and note its distribution in the respiratory system.

### Set work

Write a paragraph on the role of surfactants in the alveoli.

Notes:

## Gaseous Exchange and Exercise

### Tidal volume and vital capacity

Session:

- ▼ Tidal volume is the volume of air breathed-in and out during a single breathing cycle.
- ▼ The tidal volume increases with aerobic exercise.
- ▼ The mixing of air in the alveoli results in a fairly constant level of oxygen in the alveoli, irrespective of the point of the breathing cycle.

- ▼ The vital capacity is the greatest volume of air that can be moved in and out of the lungs in one breathing cycle.
- ▼ The tidal volume cannot approach the vital capacity as it is not possible to move such volumes of air over the lungs during rapid breathing.
- ▼ Lung volumes are closely correlated with height.

## Materials

- Supplementary Practical Sheet 10:  
**The estimation of breathing capacities using simple apparatus**
- Spirometer
- OHT Spirometer traces

The Supplementary Practical Work Sheet provides details on the measurement of tidal volume and vital capacity.

- ❑ OHT Spirometer traces for analysis of tidal volume and vital capacity provides sample traces for discussion.

Explain why the vital capacity cannot equal the total lung volume.

Notes:

## 2.3

### Gaseous Exchange and Exercise

#### Learning Outcomes (LOs)

Measurement of pulse rate as a measure of heart rate. Significance of resting pulse rate in relation to physical fitness. Systolic blood pressure, diastolic blood pressure and hypertension.

#### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ The surge of blood pumped out of the heart into the arterial system and the subsequent recoil of the arterial walls when the heart relaxes is felt as the pulse.
- ▼ The pulse rate is thus determined by the heart rate.
- ▼ The resting pulse rate is a measure of physical fitness. At rest, the metabolic demands of similar individuals are approximately the same, and are met by the cardiac output.
- ▼ The cardiac output is the product of the heart rate and the stroke volume.
- ▼ The individual with the lower resting pulse rate is meeting those demands with the same cardiac output, and must therefore have a higher stroke volume. Stroke volume is proportional to the size and power of contraction of the heart. A large powerful heart is a major component of aerobic physical fitness.
- ▼ When the ventricles contract (ventricular systole) the systolic blood pressure is generated as a result of the resistance to flow within the arterioles.
- ▼ When the ventricles relax (ventricular diastole) the pressure in the arterial system drops and is known as the diastolic blood pressure.
- ▼ These pressure changes are felt in the pulse.
- ▼ A complex of factors including a loss of elasticity in the walls of the arterial system with age, and narrowing of arteries by fatty deposits, lead to increased resistance to flow and hence higher blood pressure or hypertension.
- ▼ Short term (acute) rises in blood pressure can occur in response to specific situations as a result of anxiety, such as 'white coat hypertension' when people enter a medical environment.
- ▼ Long term (chronic) rises in blood pressure (essential hypertension), especially diastolic blood pressure, indicate a permanent rise in resistance to flow in the arterial system.
- ▼ Hypertension carries risks, particularly to the kidneys, and the brain where ruptured blood vessels result in 'strokes'.

### Student Activity

#### Materials

- Practical Work Sheet 7:  
**Measuring the Resting Pulse Rate**
- OHT Blood pressure with distance from heart

#### Procedure

Carry out the practical on the measurement of resting pulse rate.

- OHT Blood pressure with distance from heart raises issue of the importance of where the pulse rate is felt.

#### Set work

List the factors that result in the loss of blood pressure with distance from the heart.

Notes:

## Gaseous Exchange and Exercise

Leading Cause (b) (5)

### Aerobic exercise.

### Oxygen debt and the production of lactate by anaerobic respiration.

## Topic Guide

Session:

## Check List

- ▼ Aerobic exercise is at an intensity at which the demand for oxygen by the active muscles can be met by the supply of oxygen in the blood.
- ▼ Aerobic exercise is characterised by relatively low intensity for relatively long periods, during which the body is in a 'steady state', and conversation is possible.
- ▼ Anaerobic respiration occurs when the demand for oxygen by the tissues is not met by the supply of oxygen in the blood.
- ▼ Anaerobic respiration results in the rapid release of relatively small amounts of energy and the production of lactate as a by-product.
- ▼ When the intensity of exercise eases, and/or the circulatory and respiratory systems have adjusted to supply the demand for oxygen by the working muscles, the accumulated lactate is oxidised.
- ▼ The oxidation of the accumulated lactate uses a volume of oxygen equivalent to the amount that the body was short of during the anaerobic exercise.
- ▼ In this way the 'oxygen debt' is paid off.
- ▼ The excess post-exercise oxygen consumption (EPOC) is greater than the 'oxygen debt' as there are many post-exercise processes which demand extra oxygen until the metabolism returns to its resting levels.

## Student Activity

## Materials

- ❑ OHT Oxygen debt
- ❑ OHT Fast and slow twitch muscle fibres
- ❑ OHT Chicken muscles

## Procedure

- ❑ OHT Oxygen debt illustrates the various components of the so-called oxygen debt.
- ❑ OHT Fast and slow twitch muscle fibres illustrates the major demarcation between aerobic and anaerobic muscle fibres.

The nature of red and white fibres can be further illustrated with chicken breast meat (white) and thigh meat (red).

Volunteers can hold their non-writing arm in the air, and rapidly clench and release both fists. The raised arm suffers a diminished blood supply as a result of gravity, and anaerobic respiration quickly results in the accumulation of lactate, pain, and the cessation of muscle contractions. The lowered arm however shows no discomfort as it has an adequate blood supply and is respiring aerobically.

Notes:

## 2.3

### Gaseous Exchange and Exercise

#### Learning Outcomes (ILOs)

Design and carry out experiments to investigate the effects of exercise on the body.

Improving aerobic fitness.

Long term consequences on exercise on health.

#### Topic Guide

Session:

#### Check List

- ▼ Exercise experiments can be maximal or sub-maximal.
- ▼ Sub-maximal exercise experiments are safer and easier to control than maximal exercise experiments.
- ▼ Standardised exercise protocols are necessary, e.g. step test, cycle ergometer, and treadmill.
- ▼ Aerobic fitness can be improved by a simple regime of 30 minutes of steady exercise three times a week.
- ▼ Gains in aerobic fitness are lost three times more quickly than they were achieved.
- ▼ Exercise has long term benefits for health, including reduced risk of cardiovascular disease, type II diabetes, hypertension, obesity etc.
- ▼ The improved statistics associated with aerobic exercise persist only for as long as the exercise is maintained.

### Student Activity

Notes:

#### Materials

- Practical Work Sheet 8:  
**The effect of exercise on the heart rate (pulse rate) and breathing rate**
- Practical Work Sheet 9:  
**Sample plan to investigate the effects of exercise on the body.**
- Supplementary Practical Work Sheet 10:  
**The estimation of breathing capacities using simple apparatus**
- Supplementary Practical Work Sheet 11:  
**Investigating the effects of exercise on the composition of expired air**

#### Procedure

Carry out the experiments on the effect of exercise on the body.

#### Set work

Write up the experiments on the effect of exercise on the body.

## 2.4

### Smoking and disease

#### Learning Outcomes – (a) (b)

Effects of tar and carcinogens in tobacco smoke.

Symptoms of chronic bronchitis, emphysema and lung cancer.

#### Topic Guide

Session:

#### Check List

- ▼ Tar irritates the delicate epithelia of the respiratory system stimulating the production of mucus.
- ▼ Tar and mucus increase the diffusion distance, and reduce the surface area, for gaseous exchange in the alveoli.
- ▼ Chronic bronchitis is diagnosed if a chronic cough producing mucus persists for at least 3 months each year in two consecutive years.
- ▼ Emphysema is marked by the destruction of alveolar walls and the running together of alveoli to form larger air spaces, resulting in the reduction of the surface area for gaseous exchange. Airways collapse and breathing becomes laboured.
- ▼ Chronic bronchitis and Emphysema are so closely linked that they are also known collectively as 'chronic obstructive pulmonary disease'.
- ▼ Both conditions are almost entirely due to cigarette smoking.
- ▼ Lung cancer (bronchial carcinoma) can remain symptomless to an advanced stage of development, but in other cases is characterised by chest pains, blocked airways leading to breathlessness.
- ▼ The break-away of cancerous cells to form tumours at secondary sites (metastasis) is a common feature of lung cancer.
- ▼ The risks associated with smoking apply to 'passive' smoking, albeit at a lower rate.

### Student Activity

#### Materials

- Cigarette packets
- 'Smoking' apparatus

#### Procedure

Review the warnings and information on the range of cigarette packets.

Observe the 'Smoking' apparatus and the accumulation of tars in the filter.

#### Set work

Write a paragraph explaining why ex-smokers initially cough more than when they were smoking.

Notes:

## 2.4

### Smoking and disease

#### Learning Outcomes (LO)

The epidemiological and experimental evidence linking cigarette smoking to disease and early death.

#### Topic Guide

Session:

#### Check List

- ▼ Epidemiological studies can be cross-sectional across all members of a particular group, or prospective (longitudinal), following a group of subjects over a long period of time.
- ▼ Sir Richard Doll's prospective study on male Doctors started in the 1950s first raised the correlation between smoking and bronchitis, emphysema and lung cancer.
- ▼ Correlation does not prove cause and effect. Two totally unrelated effects can be perfectly correlated.
- ▼ Despite the accumulating evidence, many still resist the conclusions.

### Student Activity

Notes:

#### Materials

- ☐ OHT Risk of bronchitis with smoking
- ☐ OHT Risk of lung cancer with smoking
- ☐ OHT Improvements in statistics in ex-smokers

#### Procedure

Study the data provided in the OHTs and debate the responsibility of smokers towards passive smokers, and even the next generation via the placenta.

#### Set work

Write a paragraph countering two common assertions used by smokers to justify their habit:

- i) that it is not worth giving up smoking because one may get run over the next day;
- ii) that some people smoke heavily all their life and live to an old age with no apparent ill effects.

## 2.4

### Smoking and disease

#### Learning Outcomes (LO1) (LO2) (LO3)

Effects of nicotine and carbon monoxide in tobacco smoke on the cardiovascular system.

Reasons for the global distribution of coronary heart disease.

Balance between prevention and cure.

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Nicotine is the addictive drug in tobacco smoke.
- ▼ Nicotine stimulates the release of adrenaline and noradrenaline, which in turn result in high blood pressure, increased heart rate and cardiac output.
- ▼ Nicotine increases the levels of fatty acids in the plasma of the blood, damages the lining of blood vessels, leading to atheroma and atherosclerosis.
- ▼ Nicotine increases the tendency for the blood to clot, and hence the formation of internal clots (thromboses).
- ▼ Tobacco smoking is the major cause of leg amputation in the UK, as a result of atherosclerosis and thrombosis in the legs.
- ▼ Nicotine causes dangerous irregularities in the electrical activity of the heart.
- ▼ Carbon monoxide combines irreversibly with haemoglobin preventing its ability to deliver oxygen to the tissues.
- ▼ The combined effects of tobacco smoking greatly increases the risks of all cardiovascular disease.
- ▼ Coronary heart disease (CHD) is more common in developed countries, although exceptions exist such as France and Japan.
- ▼ CHD is closely associated with the changes in lifestyle which accompany urbanisation and increased affluence.
- ▼ Prevention is always better than cure, measures include non-smoking, reducing dietary saturated fats, keeping the BMI below 25, reducing salt intake, and increasing the amount of aerobic exercise.
- ▼ Cure involves drug therapy, coronary by-pass surgery and heart transplants.

### Student Activity

#### Materials

- ☐ OHT Heart disease risk factors chart
- ☐ OHT Questions on heart disease risk factors chart
- ☐ OHT Worldwide distribution of CHD

#### Procedure

List the risk factors for CHD and attempt to correlate them with the distribution seen on ☐ OHT Worldwide distribution of CHD

#### Set work

Write a paragraph suggesting why despite the growing body of knowledge the majority of heart attacks remain of unknown causes.

Notes: \_\_\_\_\_



## 2.5

### Infectious Diseases

Learning Objectives (LOs)

The causes and means of transmission of Cholera, Malaria, HIV/AIDS, and TB  
The worldwide importance of these diseases.

The roles of social, economic and biological factors in prevention and control. (1)

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Infectious diseases are caused by pathogens which are usually bacteria, viruses, protozoists, and fungi. They remain the leading cause of death in many developing countries.
- ▼ Cholera, malaria, HIV and TB cause large numbers of deaths but are difficult to control.
- ▼ Disease prevention involves preventing people from becoming infected. Disease control involves managing people who do have the disease to prevent its spread.
- ▼ Social, economic and biological factors all have a role in prevention and control.
- ▼ Cholera is caused by a bacterium and mainly spread through infected water and food.
- ▼ Cholera was once common in Europe but is now mainly restricted to the developing world where it causes over 100 000 deaths per year.
- ▼ Cholera spreads extremely rapidly where overcrowded conditions and poor sanitation occur: epidemics often occur in shanty towns, refugee camps and during large gatherings.
- ▼ The most effective way of preventing cholera is through improving sanitation and education about basic hygiene. A vaccine is available but is of limited value.
- ▼ Control of cholera can involve antibiotic treatment of sufferers and close contacts and isolation of cases.

### Student Activity

#### Materials

- Blank OHT sheets and pens/white board
- Transparency slides of cholera bacterium (if available).
- OHT sheet WHO definition of health

#### Procedure

The worldwide importance of infectious diseases should be discussed, also the distinction between prevention and control.

Cholera should be introduced using transparency slides of the bacterium if available.

Symptoms of the disease and the cause of death (severe dehydration) should be noted.

The idea of cholera being a disease of poverty and being relatively easy to control if basic improvements in sanitation are made (ie. social and economic factors determine its distribution: not biological ones).

Note that antibiotics and vaccinations are of secondary importance in prevention and control.

Notes:

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## 2.5

### Infectious Diseases

Learning Outcome 1 (LO1)

The causes and means of transmission of cholera, malaria, HIV/AIDS, and Tuberculosis. The worldwide importance of these diseases. The roles of social, economic and biological factors in prevention and control. (2)

### Topic Guide

Session:

#### Check List

- ▼ Malaria is caused by the single celled parasite (*Plasmodium*) and transmitted via a female mosquito vector (*Anopheles*).
- ▼ Malaria causes over 1 million deaths per year, primarily in sub-Saharan Africa, and other parts of the developing world. It was once common in the United States and parts of Europe.
- ▼ The malaria parasite lifecycle is complex and involves a sexual stage in the female mosquito and asexual stages in the liver and red blood cells of humans.
- ▼ A human can only become infected with malaria when an infected female mosquito feeds on their blood. In turn a female mosquito can only become infected if it takes a blood meal from an infected person.

### Student Activity

#### Materials

■ Microscope slides of *Plasmodium* in blood cells and of female *Anopheles* mosquito.

□ OHT Map of malarious regions

□ HT Malaria life cycle

#### Procedure

*Plasmodium* is a single celled organism (protocist) not a bacterium or virus.

□ OHT Map of malarious regions shows which areas of the world are most badly affected by the disease. Areas previously affected can also be highlighted.

□ OHT Malaria life cycle highlights the main features of the malaria life cycle, which help to explain why the parasite is so difficult to eradicate.

The concept of developmental stages occurring in both hosts should be noted, as should the role of asexual reproduction in generating huge numbers of infective parasites.

#### Set Work

It is sometimes reported that global warming could mean a return of malaria to Europe and the United States. Based on the information given in the text and on your own knowledge write a paragraph on whether you think the disease would actually prove to be a serious health risk in these regions.(note: mosquitoes are still present in Britain and malaria parasites can be transmitted by them).

Notes:

## Infectious Diseases

The causes and means of transmission of cholera, malaria, HIV/AIDS, and Tuberculosis. The worldwide importance of these diseases. The roles of social, economic and biological factors in prevention and control. (3)

Session:

- ▼ Malaria prevention and control is focused on preventing people being bitten by mosquitoes. This includes individual protective measures as well as regional, national or international efforts to control mosquitoes.
- ▼ Malaria prevention and control also uses various anti-malarial drugs. There is no vaccine.
- ▼ There are biological, economic and political reasons why malaria control is difficult.

- ▼ Biological reasons include the fact that malaria parasites acquired resistance to anti-malarial drugs, that mosquitoes acquired resistance to DDT, and that mosquitoes need only tiny amounts of water to breed.
- ▼ Malaria control is very expensive and needs years of sustained international effort and cooperation. This has often proved difficult.

Notes:

Possible control options in the mosquito life cycle (i.e. eggs laid in water and aquatic larvae) should be noted.

This disease gives opportunities to consider a broad range of control strategies at the population and individual level: biological control, chemical control, physical removal of habitat, preventative sprays, bed nets, and drugs. Most are used in combination.

List the control measures used against Malaria.

## Infectious Diseases

## Topic Guide

Session:

The causes and means of transmission of cholera, malaria, HIV/AIDS, and Tuberculosis. The worldwide importance of these diseases. The roles of social, economic and biological factors in prevention and control. (4)

## Check List

- ▼ Tuberculosis (TB) is caused by a bacterium (*Mycobacterium tuberculosis*) which infects the lung and other tissues.
- ▼ TB currently kills over 1.5 million people per year. Most of these deaths are in the developing countries but its frequency is increasing across the world.
- ▼ The disease is spread via droplets in the air, and hence is spread most rapidly in overcrowded, underventilated areas.
- ▼ Prevention of TB is focused on improving living and working conditions and improving the overall nutrition and health of individuals. A vaccine is also available but is not effective in all cases.
- ▼ Control of TB in infected patients relies on long courses of antibiotics. Often a combination of antibiotics is taken.
- ▼ Two of the reasons for increases in TB cases and deaths in the past decade have been the emergence of antibiotic resistant strains of TB and the rise of HIV/AIDS which increases susceptibility.

## Student Activity

## Materials

- #### □ OHT TB trends in England and Wales

## Procedure

TB provides a good example of how basic measures to improve overall living standards can be more dramatic than vaccines and drugs in controlling the disease.

The disease, its cause and transmission, should be covered.

- ☐ OHT TB trends in England and Wales can be used to discuss the reasons for the decline of TB, noting the dates.

Focus also on the rise in cases in recent years and the causes of this. When discussing the rise in cases in the developed world recall the fact that living conditions are very poor in some areas of the developed world.

### Set Work

In a study in New York it was found that TB was much more common in: young men who had no fixed address, who had little secondary education and who injected drugs. Explain the reasons for this. based on your knowledge of TB.

Notes:

number of comparisons

Session:

heterosexuals in the developing world, but it is infecting increasing numbers in developed countries as well.

- ▼ HIV/AIDS is caused by the HIV virus.
- ▼ AIDS is a disorder in which the body's immune system is gradually destroyed (by invasion and destruction of helper T-lymphocytes) leading to death from a range of infectious diseases.
- ▼ HIV/AIDS is a pandemic: 33 million people are affected with 2.6 million deaths in 1999.
- ▼ Most new HIV/AIDS cases are in the young

## Student Activity

- ❑ OHT Structure of the AIDS virus
- ❑ OHT Worldwide distribution of AIDS

Prior knowledge of HIV/AIDS provides an opportunity to build on that knowledge, and clarify some of the important issues.

Remember that viruses are incapable of independent reproduction and thus infect other living cells in order to reproduce.

Illustrates the worldwide significance of AIDS: Africa is currently the most seriously affected continent but cases are increasing in all regions.

Notes:

number of comparisons.

52

## 2.5

### Infectious Diseases

#### Learning Objectives

The role of antibiotics in the treatment of infectious disease

### Topic Guide

Session: \_\_\_\_\_

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#### Check List

- ▼ Antibiotics are substances produced by microorganisms which can kill or inhibit the growth of other organisms (usually bacteria).
- ▼ Bactericidal antibiotics kill other bacteria: bacteriostatic antibiotics inhibit the growth of other bacteria.
- ▼ Antibiotics are produced on a large scale using fermenters. Microorganisms producing them may be genetically engineered.
- ▼ Antibiotics were discovered in 1928 and have been in use since 1940s. Their use has caused an enormous reduction in severe illness and death from bacterial infections.
- ▼ Antibiotics interfere with essential functions of bacterial cells. They may upset synthesis of the bacterial cell wall, or prevent the production of proteins (enzymes) and nucleic acids.
- ▼ Antibiotics may be broad spectrum, killing most types of bacteria or specific to one particular species.
- ▼ Overuse of antibiotics in medicine and in farming industry has led to the emergence of some resistant strains of bacteria.
- ▼ Resistant strains of bacteria are not affected by antibiotics and hence can be very dangerous to humans as the infections they cause are untreatable and spread rapidly.
- ▼ Resistance often arises through random genetic mutations in bacterial DNA.
- ▼ Some strains of TB and *Staphylococcus aureus* are now resistant to all types of antibiotics. They are said to be 'multi-drug resistant'.

## Student Activity

### Materials

- ☐ OHT Bacterial colonies on agar plate.

### Procedure

Review the types of infections for which antibiotics are prescribed, remembering that only bacterial infections can be treated with antibiotics.

The fact that antibiotics are naturally occurring substances should also be noted as should the target sites for antibiotic action on bacteria.

- ☐ OHT Bacterial colonies on agar plate assesses the effects of antibiotics on bacterial growth on agar plates.

The larger the clear areas on the agar the more effective is the antibiotic: a resistant bacterium would not be cleared at all by the antibiotic.

### Set work.

Bacteria multiply by binary fission: one bacterium divides to form 2, 2 divide to form 4, 4 divide to form 8 etc. A person is infected with a bacterium at time X and given a bactericidal antibiotic 24 hours later. Assuming bacteria divide once every 30 minutes, and that none are destroyed or die within 24 hours calculate the maximum number of bacteria that would be present in the body by the time the antibiotic was given.

Notes: \_\_\_\_\_

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## 2.6

### Immunity

#### Learning Outcomes (LO)

Introduction and the origin, maturation, and mode of action of phagocytes and lymphocytes (1)

### Topic Guide

Session:

### Check List

- ▼ The body protects itself from becoming infected but has an immune system to attack and destroy any pathogens which do enter.
- ▼ Immunity is associated with white blood cells, particularly the phagocytes and lymphocytes.
- ▼ Phagocytes and lymphocytes are derived from stem cells.
- ▼ Stem cells are found in the liver, spleen and bone marrow.
- ▼ Stem cells are pluripotent: they can divide to form any of the different blood cell populations.

## Student Activity

### Materials

- ☐ OHT Stem cells and the origin of phagocytes and lymphocytes

### Procedure

Consider the basic defenses of the body against pathogens and link this section to that of infectious diseases in 5.2.5.

Discuss the concept of immunology, the study of the immune system of the body. This system contains both non-specific components, the phagocytes, and specific components, the lymphocytes which act to protect the body from harm caused by foreign material, especially pathogens.

- ☐ OHT Stem cells and the origin of phagocytes and lymphocytes introduce the concept of the pluripotent stem cell, a type of cell which can divide to form many different cell types.

Phagocytes and lymphocytes as well as red blood cells (to be studied in section 5.3) arise from these stem cells in regions including the liver, spleen and bone marrow.

### Set Work

List the areas in the body where phagocytes and lymphocytes are found.

Notes:



## 2.6

### Immunity

#### Learning Outcome (A)

Introduction and the origin, maturation, and mode of action of phagocytes and lymphocytes (2)

### Topic Guide

Session: \_\_\_\_\_

### Check List

- ▼ Phagocytes are characterised by a lobed nucleus and grainy cytoplasm.
- ▼ Phagocytes engulf and digest pathogens in a non-specific fashion.
- ▼ Phagocytes are found in blood as well as other tissues.
- ▼ Lymphocytes are characterised by a large dense nucleus and non-grainy cytoplasm.
- ▼ There are B and T lymphocytes, both of which are involved in specific immune responses.
- ▼ After maturing in bone marrow, lymphocytes migrate to the lymph nodes.
- ▼ B-lymphocytes migrate directly, T-lymphocytes move via the thymus gland.
- ▼ Lymphocytes are found in blood and lymphatic system, especially in lymph nodes.

## Student Activity

### Materials

- Microscope (with magnification up to x400)
- Slides of blood smears.
- Histology books (optional)
- OHT Phagocytes and lymphocytes.

### Procedure

Examine blood cells under the microscope.

Note that blood smear slides aim to display a very thin film of blood (one cell deep) across a slide. White cells are not visible unless stained. Nuclei of white cells show blue-purple.

View blood slide under high power. Try to identify a lymphocyte (large, almost spherical nucleus) and a phagocyte (lobed nucleus). Compare their features and compare both with red blood cells. Sketch both types of white blood cell from the slide.

Compare the numbers of the white blood cells with the red blood cells which fill the field of view. Try to estimate how many more red blood cells there are compared to white.

It is notoriously difficult to focus microscopes on slides of blood cells. Use the fine focus once a red blur is seen.

It is possible that a single field of view contains no white blood cells.

### Set work

Make a series of annotated drawings illustrating phagocytosis.

Notes: \_\_\_\_\_

## Immunity

## The immune response

Session:

- ▼ B and T lymphocytes recognise foreign material in the body.
- ▼ Foreign material is detected by the presence of foreign surface antigens.
- ▼ Antigens are usually protein molecules found on the surface of all cells which may be pathogens or other human cells. Viruses and non-living material may also possess antigens.

- ▼ An immune response occurs when lymphocytes detect the presence of foreign antigens and set in motion mechanisms to destroy the foreign material.
- ▼ The immune system is important in protecting the body from the damaging effects of pathogens and other foreign materials.

Notes:

Discuss the circumstances under which foreign material enters the body and the modes of entry of such material to the body.

This should include a consideration of infection by pathogens as well as entry of foreign cells via blood transfusions, organ transplants

Organs transplanted from one sibling to another may be 'rejected' whilst those from one identical twin to another are not. Find out why this is..

## Immunity

### The action of B-lymphocytes and T-lymphocytes in fighting infection: B-lymphocytes

## Session:

- ▼ The type of immune response associated with B-lymphocytes is termed humoral immunity and involves the production of antibodies.
- ▼ There are thousands of different types of B-lymphocyte, and each type will only recognise one specific type of antigen.
- ▼ B-lymphocytes have antigen receptors which detect and bind to foreign antigens.

- ▼ Binding of antigen to antibody activates the B-lymphocyte, causing it to divide.
- ▼ B-lymphocytes in the clone divide into either plasma cells or memory cells
- ▼ Plasma cells secrete specific antibodies against the pathogen
- ▼ Memory cells remain in the body in case of future infection with the same pathogen.

## Materials

- OHT B-lymphocyte action: sequence of events

□ OHT B-lymphocyte action illustrates the sequence of events in the response of B-lymphocytes to a pathogen.

Note the specific complementary shape of the antigen receptors on the lymphocyte surface and the antigen on the pathogen surface.

The OHT can be annotated to show how a pathogen with a different shaped antigen will not fit the receptor.

The production of a large clone of lymphocytes by mitosis is a vital part of the process.

Note that only plasma cells can secrete antibodies, that antibodies are protein molecules, and that antibodies have no capacity for directly killing pathogens.

B-lymphocytes divide by mitosis to form a clone when their specific antigen is encountered. Define the term 'clone' and explain why it is important for a B-lymphocyte to form a clone.

Notes:

## Immunity

### The action of B-lymphocytes and T-lymphocytes in fighting infection: T-lymphocytes

Session:

- ▼ T-lymphocytes are associated with cell mediated immunity: the direct killing of infected cells.
- ▼ As with B-lymphocytes, there are many types of T-lymphocytes, each being specific to one antigen.
- ▼ T-lymphocytes can only recognise foreign antigens when presented on the surface of a human cell by an MHC molecule. Recognition involves specific antigen receptors.

- ▼ When a T-lymphocyte is activated by binding to its specific antigen it will proliferate to form a clone of identical cells.
- ▼ T-lymphocytes may destroy infected cells by releasing lytic enzymes.
- ▼ There is co-operation between T-lymphocytes and other components of the immune system including helper and suppressor T lymphocytes, phagocytes and B-lymphocytes.

Notes:

- OHT T-lymphocyte function: sequence of events

- ❑ OHT T-lymphocyte function: illustrates the sequence of events in the response of T-lymphocytes to a pathogen.

Note the similarities with B-lymphocytes in terms of recognition of specific antigens leading to proliferation.

Note the differences: T-lymphocytes can only recognise antigens in association with MHC proteins on human (self) cells, and T-lymphocytes do not produce antibodies but kill cells more directly.

Annotate OHT to show how helper and suppressor T-lymphocytes might affect the process.

1. The HIV virus infects and kills helper T-lymphocytes. Using knowledge of HIV/AIDS from 5.2.5. and knowledge of lymphocytes explain why this leads to illness and death from a range of pathogens.
2. Using knowledge of B and T-lymphocytes explain why the lymph glands in the neck become swollen during infections.

## Immunity

### The role of memory cells in long term immunity

Session:

- ▼ Both B and T-lymphocytes form memory cells during a first encounter with an unfamiliar pathogen. These remain in the body in case of future encounters with the same pathogen.
- ▼ Memory cells are activated if the pathogen is encountered again.
- ▼ T-lymphocyte memory cells divide to form new functional T-lymphocytes.

- ▼ B-lymphocyte memory cells form new plasma cells which secrete antibodies.
- ▼ The secondary antibody response is more rapid and larger than the primary response.
- ▼ Memory cells can provide life-long immunity to some pathogens but not to others.
- ▼ The production of memory cells can be stimulated naturally or artificially via vaccination.

## Materials

- OHT Primary and secondary immune responses

□ OHT Primary and secondary immune responses illustrates the concept of primary and secondary responses of B-lymphocytes.

Note the importance of the pattern shown with reference to the speed of the secondary response and the concentration of antibody produced.

Note how the delay is so short that a person would often not even know they had encountered the pathogen before the body had mounted an immune response. The concept of vaccination could be considered here.

Group discussion: a discussion on the diseases to which they think they are immune (as a result of previous infection rather than vaccination) and which they are not. This could centre on the idea of comparing the number of times you have had chickenpox/mumps/measles with how many times have you had a cold/flu.

1. Why is it important that not all the memory cells turn into plasma cells on the second encounter with a pathogen?
2. Explain why immunity to measles does not protect you from chicken pox.

Notes.

### Learning Outcome 12

## Session:

## The molecular structure of antibodies and their function

- ▼ Antibodies are produced by plasma cells in response to specific antigens.
- ▼ Antibodies are a type of globular protein molecule called immunoglobulins which are made up of 4 polypeptide chains.
- ▼ Antibodies are shaped like a Y. The tail of the Y is the constant region and is always identical.

▼ Antibodies do not directly destroy pathogens but achieve this in interaction with other components of the immune system.

Notes:

- OHT Antibodies bind pathogens together.

Note that variation in the binding sites arises from slight differences in the amino acid sequences of the polypeptide chains making up the immunoglobulin.

This in turn must reflect slight differences in the DNA of each type of B-lymphocytes which produce the antibodies.

Antibodies function to aid destruction of pathogens within a coordinated immune system.

One of their modes of action is to bind pathogens together for ingestion by phagocytes; another is to stimulate the production of chemicals known as 'complement' which lyse pathogens.

A third is to bind to pathogens at sites critical to infection of host cells, thus rendering them inactive.

Blood groups A, B and O have antibodies in the plasma against the opposite antigens, e.g. A has anti-B antibodies, B has anti-A antibodies and O has both types of antibodies. Explain what is unusual about this situation.

## Immunity

Active and passive immunity, natural and artificial immunity and the use of vaccination to control disease. (1).

## Session:

- ▼ Natural active immunity, involving memory cells, results from a natural infection with a pathogen.
- ▼ Artificial active immunity, which also involves memory cells, is provided by vaccination.
- ▼ Vaccination is the process whereby a small quantity of material from a pathogen is deliberately introduced into the body in order to stimulate lymphocytes to make an immune response.

- ▼ Vaccines may contain dead pathogens, live attenuated pathogens, or toxins or antigens from pathogens.
- ▼ Genetic engineering is used in the production of some vaccines.
- ▼ Vaccines generally provide a safe and effective way of gaining immunity to a disease.

## Notes:

Recap on the nature of the immune response to pathogens and the importance of memory cells (B and T).

Discuss the principle of vaccination and how it mimics the process of natural active immunity without the risk of actually contracting the disease.

Review the different forms of vaccine available (dead pathogen, live attenuated pathogen, toxin from pathogen, antigens from pathogen).

Discuss the possible pros and cons of such different vaccine types. Note the need to produce a strong immune response balanced against the need to make a safe vaccine.

Find out the vaccinations which are recommended for children in Britain and the ages at which these are given. Suggest reasons for the different ages of vaccination.

## Immunity

Active and passive immunity, natural and artificial immunity, and the use of vaccination to control disease. (2)

Session:

- ▼ Passive immunity involves the provision of ready made antibodies to a person.
- ▼ Passive immunity does not stimulate lymphocytes or memory cells. It is short term.
- ▼ Natural passive immunity is provided for a foetus when antibodies cross the placenta, or for a baby via antibodies in colostrum.
- ▼ Artificial passive immunity involves a person being injected with antibodies against a disease he/she has or is at risk of in the short term.

- ▼ The principle of vaccination was first scientifically demonstrated by Jenner in 1796.
- ▼ Since Jenner, vaccination has had a dramatic impact on deaths from a range of infectious diseases, especially in childhood.
- ▼ A vaccination will prevent an individual getting ill or dying from an infectious disease but it can also control the disease within the community or region if people cooperate.

## Procedure

Focus on the short term nature of this type of protection.

Remember the provision of antibodies to a baby via breast milk is an important reason for breastfeeding.

Briefly discuss Jenner's work. Highlight the fact that he used circumstantial evidence (milkmaids immune to smallpox) in formulating his theory and that, as with most discoveries he was not the only person who had the idea of protecting people against smallpox in this way. Note that it is very rare for infection with one disease to stimulate immunity to another (this is an exception to the specific nature of antigens).

### Set work

Ten years ago there was no suitable vaccination against hepatitis B. Instead people were injected with antibodies against this virus which had been produced in the blood of a rabbit. Write a paragraph on why the new genetically engineered vaccine is much more successful at protecting people against the disease than the former strategy.

Notes:



## 2.6

### Immunity

#### Learning Outcome 11

Reasons why vaccination has eradicated smallpox but not measles, TB, malaria or cholera

### Topic Guide

Session: \_\_\_\_\_

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### Check List

- ▼ Only one disease has been eradicated by vaccination: smallpox, declared eradicated in 1979.
- ▼ Biological reasons for smallpox eradication include the fact that the disease was recognisable, the virus was very stable, had no non-human reservoirs or long term carriers. The vaccine was very effective, provided life-long immunity, and injection created a distinctive scar.
- ▼ Economic/political factors included a highly coordinated international eradication programme.
- ▼ The success of smallpox eradication has not been repeated for other diseases. Reasons for this are social and economic as well as biological.
- ▼ Measles is highly contagious with a short incubation period. Eradication would require over 95% of people to be vaccinated in all regions. This is highly unlikely in the developed world as the disease is not always considered serious and parents opt out of vaccination.
- ▼ So far it has not been possible to produce an effective malaria vaccine. One reason for this is that the malaria parasite constantly changes its surface antigens, preventing memory cells from functioning effectively. It is also a vector borne disease occurring in poor countries.
- ▼ Cholera is a highly contagious disease with symptomless carriers and non-human reservoirs. It is a disease of poverty and would be most effectively controlled by improved sanitation. The current cholera vaccine, using a dead bacterium does not provide complete immunity.
- ▼ Tuberculosis has both symptomless human carriers and a non-human (bovine) reservoir. It is not always recognisable in early stages, and had ceased to be considered important in the developed world until a few years ago. The vaccine is not 100% effective.

## Student Activity

### Procedure

Discuss the eradication of smallpox in terms of the massive international nature of the programme as well as the biological characteristics of the disease.

### Set Work

Discuss the reasons why measles, malaria, cholera, and TB are unlikely to be eradicated.

Emphasise in particular the interactions between biological and socio-economic factors.

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## Immunity

### Role of the immune system in allergies, with reference to asthma and hay fever

Session:

- ▼ Protective inflammatory responses occur when non-pathogenic antigens (eg. toxins in bee stings) are encountered. This leads to swelling and leakage of tissue fluid in affected areas.
- ▼ In some individuals severe (even life-threatening) inflammatory responses are stimulated by antigens on common materials such as pollen and some foods. This is the basis of allergies.
- ▼ Hay fever is a common allergy caused by antigens on pollen grains. Specific IgE antibodies are produced in response. These bind to mast cells and cause release of histamine.
- ▼ Histamine causes irritation and swelling of the mucous membranes of eyes and nose and release

- ▼ Hay fever can be treated with anti-histamine drugs.
- ▼ Asthma is a difficulty in breathing caused by constriction of bronchioles.
- ▼ Asthma can result from allergic reactions. Histamine causes the linings of the bronchioles to swell, and secrete excess mucus and causes the smooth muscle in the walls of the bronchioles to contract. All three features reduce air flow into and out of lungs.
- ▼ Drugs to reverse these effects, 'bronchodilators' can be taken via inhalers.

Notes:

- Microscope and slides of pollen grains
- A ventolin inhaler (optional)

Discuss basics of inflammatory responses.

Describe and explain the reactions of the body to an insect bite/nettle sting/ wasp sting. i.e. area is raised/swollen/itchy/hot.

Introduce the concept of allergies and gather information on allergies.

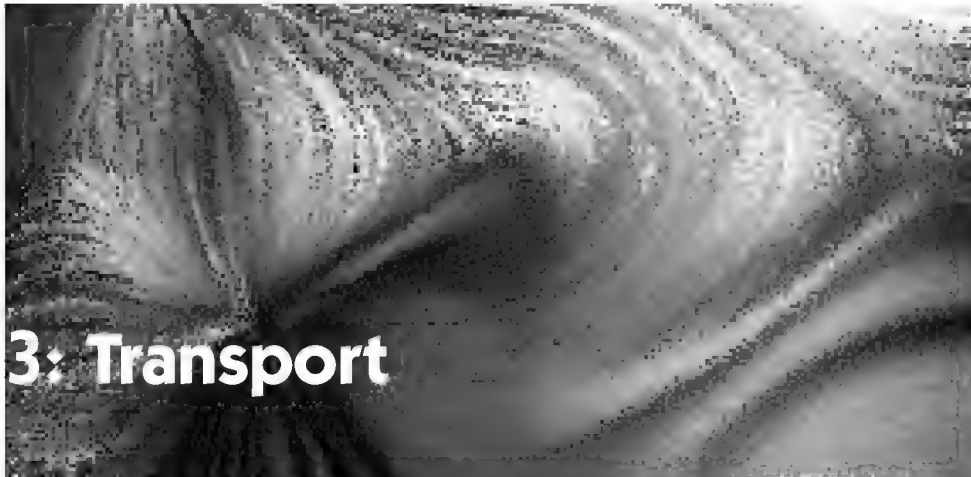
Consider the changes in the bronchioles that occur in asthma.

Discuss the reasons why asthma is treated with drugs in inhalers and other allergies by drugs taken by mouth.

Write a paragraph on the controversy surrounding the use of asthma inhalers in competitive sport.

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# Topic Guides



## **3.1 The Mammalian Transport System**

## **3.2 The Mammalian Heart**

## **3.3 Transport in Multicellular Plants**

### 3.1

## The Mammalian Transport System

### Learning Outcomes (A)

The need for transport systems in multicellular animals in terms of size and surface area to volume ratios

### Topic Guide

Session:

### Check List

- ▼ Surface area increases with size but the surface area to volume ratio decreases with size.
- ▼ SA/V increased by flattened body shapes and structures.
- ▼ Where SA/V sufficiently large, simple diffusion suffices for exchanges with environment and internal transport.
- ▼ Discussions of development of transport systems also involve level of complexity of organism.
- ▼ Development of transport systems involves pumping hearts and tubes.
- ▼ Development of transport systems involves development of specialised exchange surfaces with large surface areas.
- ▼ Diffusion still important in all exchanges, but not in transport throughout volume of organism.

## Student Activity

### Materials

- 3 pieces of paper per student sized A4, A5 and A6
- Adhesive tape and scissors.
- OHT Cubes 2cm and 1cm sides

### Procedure

Make three cylindrical 'animals' from the different sized pieces of paper. Roll the paper in each case taping the short ends together to make three 'animals' of similar shape and different size. Now calculate the surface area to volume ratio, making out a table like this:

| Surface area<br>(mm <sup>2</sup> ) | volume of cylinder<br>( $\pi r^2 \times \text{length}$ ) | surface area /volume<br>(mm <sup>3</sup> ) |
|------------------------------------|----------------------------------------------------------|--------------------------------------------|
|                                    |                                                          |                                            |
|                                    |                                                          |                                            |
|                                    |                                                          |                                            |

What trend can you recognise? Untape the A4 paper and roll it up lengthwise so that it makes a longer, thinner 'animal'. Calculate the surface area/ volume ratio of this and compare it to that of the other A4 'animal'. What is the difference? Why is there a difference?

Make up two sets of jelly cubes of different size but from the same volume of jelly with a soluble dye (methylene blue). Wash well, place in water, and observe release of dye. Relate your observations to surface area/volume ratio considerations.

Now relate all this to the question of obtaining nutrients and oxygen in solution, getting rid of soluble waste etc. i.e. exchanging materials with the outside environment (assume it's an aquatic 'animal'). You should come to see that the smaller the surface area/volume ratio, the greater the need for a transport system.

What factors other than size affect the need for a transport system? Consider the importance of shape (see results of the A4 cylinders) and the level of activity, i.e. the rate of exchange needed.

### Set work

Write 10 lines on 'Specialised exchange surfaces in the human body'.

Notes:

## The Mammalian Transport System

### Structure of arteries, veins and capillaries and their recognition using the light microscope

## Session:

- ▼ Arteries have thick elastic walls with smooth muscle.
- ▼ Arteries are lined with smooth endothelium common to all blood vessels.
- ▼ Arteries divide into smaller branches leading into arterioles
- ▼ Capillaries form networks or beds in all tissues particularly rich in active tissues and alveoli of lungs

- ▼ Walls of capillaries are one cell thick.
- ▼ Diameter of capillaries of 6 - 8  $\mu\text{m}$ , the same as that of red blood cells.
- ▼ Capillaries drain into venules which in turn drain into veins.
- ▼ Veins have thin elastic walls with much less muscle than arteries.
- ▼ Veins have relatively larger lumen than arteries.
- ▼ Pocket valves occur at intervals in larger veins.

## Materials

- Microscope slides of TS artery and vein
  - Microscope slides of TS alveoli and TS kidney glomeruli
  - Practical Work Sheet: 12
- The observation of arteries, veins and capillaries under the light microscope**
- OHT Structure of arteries, veins and capillaries

TS Artery and Vein often on same slide.

Artery recognised by wavy black lines of elastic tissue in thicker walls in typically stained slides.

Lining often slightly corrugated as a result of shrinkage of artery during slide preparation.

Veins comparatively so large and thin walled they can be overlooked as a large space in the tissue.

Pocket valves rarely seen in TS.

Capillaries only clearly seen in section of alveoli or kidney glomeruli, both regions of large exchanges of gases and fluid respectively.

Can observe functioning capillaries in tadpole tails if right time of year (March/April).

Make line drawings of each type of vessel paying careful attention to linear magnification of final drawings.

Calculate the relative diameters of each vessel in terms of the number of times greater than that of a capillary (6-8  $\mu\text{m}$ )

Notes:

### 3.1

## The Mammalian Transport System

Learning Objective (LO)

Functions of arteries, veins and capillaries in relation to their structure

### Topic Guide

Session:

### Check List

- ▼ Elastic arteries stretch with the blood surge from the heart when the ventricles contract, and then recoil, these movements being felt as the pulse
- ▼ Finer branches and arterioles main site of generation of resistance to blood flow.
- ▼ Capillary beds supply all tissues providing large surface areas for exchanges by diffusion and short diffusion distances.
- ▼ Capillaries have large total cross sectional surface areas. Therefore resistance to flow, blood pressure and rate of flow all drop in capillaries.
- ▼ Diameter of capillary same as red blood corpuscles
- thus forcing them to pass through capillaries in single file, bringing all close to tissues.
- ▼ Plasma minus proteins exuded through thin walls to bathe tissues directly.
- ▼ Thin walls and large lumen of veins offer little resistance to flow of blood back to heart, and allow ease of massage by surrounding muscles.
- ▼ Pocket valves in veins ensure one way flow back to heart.
- ▼ Venous blood under low pressure but flow fast enough to ensure return of blood to heart at same rate as blood flow in the arteries.

## Student Activity

### Materials

- 2mm (ring) sections cut from the aorta and vena cava of a sheep/pig's heart in saline
- 40 cm length of fishing line.
- Assorted weights (10 to 100g) and hook for their suspension.
- Retort stand and 2 clamps.
- Ruler

### Procedure

Investigation into stretch and recoil of arteries and veins.

Set up a retort stand with the section of artery or vein suspended by the fishing line to a clamp. A second piece of fishing line is used to suspend different weights from the vessel. A ruler is positioned and clamped to enable any stretching of the vessel to be measured. The exercise consists of adding weights to the line. Measure the distance stretched as a 10g weight is added and record it as a percentage of the original vessel length, then take off the weight and measure how far the vessel recoils. Record this also as a percentage of the original vessel length. Repeat, increasing the weight

by 10g each time. How do the stretch and properties of arteries a veins differ. Suggest a reason.

### Set work

Make a table to compare the structure and properties of arteries, veins and capillaries.

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## 3.1

### The Mammalian Transport System

#### Learning Outcomes (LO)

The composition of blood, tissue fluid and lymph

#### Topic Guide

Session:

#### Check List

- ▼ Blood consists of fluid plasma with red blood cells, white blood cells (or white cells) and blood platelets.
- ▼ Plasma contains 10% materials in suspension and solution.
- ▼ Plasma proteins have a wide variety of functions and act to buffer changes in pH.
- ▼ Materials carried in solution in the plasma are not strictly part of the plasma.
- ▼ Red blood cells lose nucleus in development and become biconcave corpuscles of haemoglobin.
- ▼ Large surface area to volume ratio individually due to biconcave shape, and huge total surface area due to small size (6-8  $\mu\text{m}$ ) and large numbers.
- ▼ Red blood cell volume 30-50% of total blood volume.
- ▼ Males higher blood count/haemoglobin than females.
- ▼ White cells (of which there are several types) form basis of immune system (see section 5.2.6)
- ▼ Platelets are fragments of white cells.
- ▼ Tissue fluid basically plasma minus its proteins.
- ▼ Lymph is tissue fluid that has been drained into lymphatic capillaries, with lymphocytes added by lymph nodes which are part of the immune system.

### Student Activity

#### Materials

- Slide of stained blood smear.
- OHT Blood components
- OHT Diagram showing relationship between blood and lymph

#### Procedure

Observe slide of stained blood smear with aid of OHT showing structure and function of red cells, lymphocytes, phagocytes and platelets.

Red blood cells are amongst the smallest things you will see in this course, and the microscope must be carefully adjusted.

White cells are widely scattered and typically stained blue, especially the nucleus. It may be difficult to differentiate between the different types.

Platelets may just be seen under high power (x40) objective lens as tiny granules.

Use OHT to understand how tissue fluid and lymph are formed. Explain the meaning and differentiate between the terms blood, plasma, tissue fluid and lymph.

Consider the blood vessels and lymph vessels of a working muscle. Discuss what might happen to the following blood components which enter via the artery:

- a) a molecule of glucose
- b) a molecule of oxygen attached to haemoglobin
- c) a molecule of water from the plasma

#### Set work

Explain how the lymphatic system helps to maintain a relatively constant blood volume

Explain why this is important.

Notes:

### 3.1

## The Mammalian Transport System

### Alveoli and gas exchange

### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Gas exchange occurs over large surface area of alveoli which is a product of their relatively small size and large number.
- ▼ Diffusion gradients of oxygen and carbon dioxide dependent upon partial pressures of gases on either side of diffusion surface.
- ▼ Diffusion surface composed of thin squamous epithelium ridged around the sandwiched capillaries.
- ▼ Surface water (an inevitable consequence of a permeable surface exposed to air) decreases diffusion of oxygen more than the diffusion of carbon dioxide.
- ▼ Air in alveoli remains fairly constant in composition independent of breathing cycle.
- ▼ Diffusion gradients are maintained by circulating blood and ventilation of lungs.
- ▼ As demand for oxygen increases so does steepness of diffusion gradients and speed of circulation thus meeting extra demand.

## Student Activity

### Materials

- Microscopes
- Slides TS alveoli
- OHT Diagram of alveoli and associated capillaries

### Procedure

Use OHT showing the structure of alveoli and associated capillaries to help interpretation of microscope slide of TS alveoli. A copy of the OHT diagram could be annotated as the lesson progresses. Compile a list of factors which affect the rate at which oxygen diffuses from the alveolar space to combine with haemoglobin in a red cell in the capillary. Including: relative concentration of oxygen (partial pressures), distance to be travelled, surface area for exchange, speed of blood flow, ventilation rate.

Consider the diffusion of oxygen in a theoretical situation where the blood and air are static. The rate would depend entirely on the surface area, the concentration gradient, the distance and the degree of oxygenation of haemoglobin. Now consider what happens in actual situation with air and blood moving. Remember that during exercise there may be a large increase in oxygen uptake per minute. The faster the air is refreshed and the blood is moved,

the greater the rate of oxygen uptake. Annotate a copy of the diagram by way of making notes on this lesson.

### Set work

In the disease emphysema the alveoli run together to form larger air sacs. Explain, the effect this has on the surface area of the lung for gas exchange, illustrating your answer with simple diagrams and calculations.

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### 3.1

## The Mammalian Transport System

Learning Outcomes (LO1) (LO2) (LO3)

Haemoglobin - oxygen and carbon dioxide transport

### Topic Guide

Session:

### Check List

- ▼ Reversible combination of haemoglobin and oxygen is a physical association.
- ▼ During all exertions at sea level the haemoglobin in blood leaving the lungs is virtually always saturated, so that efficiency of lungs not normally a limiting (rate regulating) factor in exercise.
- ▼ Gas exchange at tissues in effect the reverse of that at the lungs, similarly explained in terms of diffusion gradients (partial pressure gradients).
- ▼ Bohr effect applied to conditions in tissues illustrates how conditions of increasing temperature and decreasing pH reduce the affinity of haemoglobin for oxygen ie oxygen is released to tissues.
- ▼ Fetal haemoglobin has a greater affinity for oxygen than adult haemoglobin therefore 'robs' it of oxygen. Note that the placental artery is some distance from the lungs of the mother.
- ▼ Haemoglobin also has a role in transport of carbon dioxide as carbaminohaemoglobin.
- ▼ Reduction of oxygen partial pressure at altitude stimulates release of EPO hormone which promotes red blood cell production by red bone marrow to compensate for reduced availability of oxygen (reduced partial pressure of oxygen in alveoli).

## Student Activity

### Materials

□ OHT

- (i) Normal dissociation curve
- (ii) Bohr effect
- (iii) Fetal haemoglobin dissociation curve.

### Procedure

Revise structure of haemoglobin. Revise the four possible attachment sites for oxygen on each molecule of Hb. When all the sites on all the molecules are occupied the blood is 100% saturated. □ OHT shows that this situation is obtained in the lung alveoli. Where oxygen is being used by respiring tissues a concentration gradient develops with the result that oxygen dissociates from Hb and diffuses into the tissues. Annotate a copy of the OHT chart.

Bohr effect. Note the effect of increasing carbon dioxide on the dissociation of oxygen using the □ OHT. Annotate a copy of this OHT.

Fetal haemoglobin. Note the difference between adult and fetal Hb using the □ OHT. Annotate a copy of this OHT.

Remember that these curves are to be looked at as 'loading' with oxygen at the lungs from left to right; and 'unloading' oxygen at the tissues from right to left.

### Set work

With increasing altitude, the partial pressure of oxygen in the air decreases (oxygen still accounts for 20% of the air but it is less dense). At 5500m. the partial pressure of oxygen reduces to a half of its value at sea level.

1. What would the percentage saturation of blood haemoglobin be at this altitude?
2. How are people who live at high altitudes e.g. in the Andes or Himalayas adapted to low oxygen partial pressures?
3. What should high altitude climbers do to prepare themselves for the effect of reduced oxygen levels?
4. How do these principles relate to modern athletics training?

Notes:

## Learning Objective (a) (b)

## Topic Guide

Session:

- ▼ Atria walls thinner than ventricle walls.
- ▼ Left ventricle wall is thicker than right ventricle wall to pump blood around entire body (systemic circulation).
- ▼ Right ventricle wall is thinner as only has to pump blood via pulmonary circulation around lungs, where reduced pressure prevents formation of tissue fluid in alveoli.
- ▼ Volumes of both left and right ventricles the same as right ventricle supplies the left ventricle with blood via the lungs and left atrium.

Notes:

## 3.2

### The Mammalian Heart

#### Learning Outcomes - (c)

The closed double mammalian circulation

#### Topic Guide

Session: \_\_\_\_\_

#### Check List

- ▼ Closed double mammalian circulation more efficient than open single circulation.
- ▼ Open circulation has blood returning to heart in large open blood spaces (haemocoel), slow flow and low pressure.
- ▼ Compensated for in insects by tracheal system delivering oxygen gas (in air) directly to tissues.
- ▼ Single circulation blood only passes through heart once on each complete circulation of the body.
- ▼ Means that blood passes through two sets of capillaries on each circulation, respiratory surface and body tissues.
- ▼ Represents large resistance to overcome before blood returns to heart, resulting in slow flow and low pressure in veins which are typically large blood sinuses to lower resistance to flow.
- ▼ Closed systems blood almost entirely restricted to vessels: arteries, arterioles, capillaries, venules, veins.
- ▼ Tissue fluid exuded to bathe tissues directly.
- ▼ Double circulation blood passes through heart twice on each circulation.
- ▼ Pressure relatively low to lungs.
- ▼ Pressure raised for systemic circulation to body giving high pressure and fast flow.

## Student Activity

### Materials

- ☐ OHT Mammalian heart
- ☐ OHT Closed double circulation diagram

### Procedure

☐ OHT Closed double circulation. Explain the advantages of a double circulation (it only occurs in birds and mammals - the 'warm blooded' vertebrates) Now relate this diagram to the structure of the heart using the ☐ OHT.

### Set work

Write 10 lines on 'Why the human heart can be considered as two separate pumps.'

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## The Mammalian Heart

Learning Outcomes: (d)

## The cardiac cycle

## Topic Guide

Session:

## Check List

- ▼ The events of a complete filling and emptying of the heart are known as the cardiac cycle.
- ▼ Continuous cycle start point of which can be taken when heart is empty and all valves shut.
- ▼ Atria fill and internal pressure rises forcing bicuspid and tricuspid valves open.
- ▼ Ventricles fill so that whole heart full.
- ▼ Atria contract (atrial systole) so that ventricles overfilled and stretched.
- ▼ Ventricles contract with a force proportional to their degree of stretch (ventricular systole).
- ▼ Blood forced up shutting bicuspid and tricuspid valves (first heart sound) and opening pocket valves as blood forced into pulmonary artery and aorta.
- ▼ Ventricles relax (ventricular diastole) blood falls back in pulmonary artery and aorta shutting pocket valves (second heart sound).

## Student Activity

## Materials

- Blood pressure measuring device
- Stethoscope
- OHT Graph/chart of the cardiac cycle

## Procedure

Listen to heart sounds using stethoscope. Relate sounds to valve closures and stages of cardiac cycle.

Demonstration of the measurement of systolic and diastolic blood pressure. Note the limitations of single readings in stressful conditions.

Demonstration of venous blood pressure:

stand back to a wall and raise arm to level with heart. At this point veins in hand and arm should still be visible (if visible in the first place). Mark this position. Get an assistant to raise the arm until veins 'collapse' mark this new position. Note the distance (d) between the two marks in cms. Calculate the venous blood pressure from:

$$(d-10) \times 1.055 / 13.55 \times 10 = \text{answer in mm.Hg}$$

### Set work

Record your pulse rate before rising each morning and just before going to bed each evening for a week, and plot as a graph of pulse rate against time.

Notes:

## The Mammalian Heart

Learning Outcomes: (a)

### Initiation and control of heart action

## Topic Guide

Session:

## Check List

- ▼ Cardiac muscle is myogenic.
- ▼ Rate modified by sinu-atrial node (pacemaker) in wall of right atrium.
- ▼ Waves of electrical activity spread rapidly down through cardiac muscle of atria.
- ▼ Prevented from passing directly into ventricles by barrier of connective tissue, stimulus picked up by atrio-ventricular node.
- ▼ Bundle of His composed of Purkyne tissue transmits stimulus to base of ventricles from

where it radiates up through the walls back to the connective tissue barrier.

- ▼ Electrical activity detected as an ECG by electrodes on the skin.
- ▼ Pacemaker influenced by sympathetic (faster) and parasympathetic (slower) nervous systems, and the hormone adrenaline.
- ▼ All influences on heart rate, coordinate heart rate and therefore blood supply to body (cardiac output), with demands of body.

## Student Activity

## Materials

- ECG charts
- OHT Diagram of electrical activity in heart

## Procedure

Observe how the nerve message is transmitted through the heart with the aid of the OHT. Annotate a copy of this OHT

Observe copies of ECG charts (in groups) and explain how they are obtained.

Relate the ECGs to the events illustrated on the OHT.

## Set work

Artificial pacemakers re-establish a fixed rhythm in those suffering erratic heart beats. Explain the effect on daily activities of having an artificial pacemaker fitted.

Notes:

### 3.3

## Transport in Multicellular Plants

### Learning Outcomes (LO)

The need for transport systems in multicellular plants in terms of size and surface area to volume ratios

### Topic Guide

Session:

### Check List

- ▼ Principles of relationship between size, shape and surface area to volume ratio hold for plants as previously discussed with animals.
- ▼ Situation in plants complicated by terrestrial plants being rooted in soil from which they absorb water and inorganic ions (minerals) with aerial parts (leaves) for photosynthesis, which renders transport systems necessary independent of size.
- ▼ Large plants (trees) have large surface area to volume ratios as a result of their leaves, but still have transport systems as diffusion is insufficient to account for the rate of transport throughout the plant.
- ▼ Xylem transports water from roots to leaves.
- ▼ Phloem transports organic compounds (assimilates) e.g. sucrose from leaves or storage organs to regions where respiration predominates e.g. growing tips of roots and shoots.
- ▼ Transport in xylem unidirectional (from roots to leaves).
- ▼ Transport in phloem in both directions.

## Student Activity

### Materials

- Microscopes
- Hand lenses
- Fresh samples of pond weed or water lily, moss, fern, various non-woody shoots.
- A woody twig

### Procedure

Examine the plant material with microscope or hand lens as appropriate.

Note the nature and 'feel' of the material and relate these observations to the various habitats in relation to water supply.

Note that the moss sporangium is the equivalent diploid phase of the life cycle as the fern plant and all other land plants including trees.

If slides available examine them for presence of vascular tissue.

If water lily available cut into stems and notice nature of tissue compared to fern stem.

Place a variety of cut stems in coloured dye and observe its ascent in the stem by teasing the tissue apart after a certain time period.

### Set work

Explain why it is difficult to explain the presence of transport systems in multicellular plants solely on the basis of surface area to volume ratio.

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### 3.3

## Transport in Multicellular Plants

### Learning Outcomes (LO)

#### Transpiration

### Topic Guide

Session:

#### Check List

- ▼ Transpiration is the loss of water vapour from the leaves.
- ▼ It is an unavoidable consequence of having stomata opening for the uptake of carbon dioxide (and release of oxygen) in the light.
- ▼ Evaporation maintains the upward movement of water column in xylem - the transpiration stream.
- ▼ Transpiration stream provides for upward transport of water and dissolved inorganic ions (and some organic compounds) from roots to leaves.
- ▼ Evaporation from leaves provides some cooling effect, but not when most needed as stomata shut and leaves wilt in conditions of extreme heat.
- ▼ Transpiration rate affected by any factor that affects evaporation of water: relative humidity, temperature, air speed, availability of water, light intensity, degree of opening of stomata, number and distribution of stomata.

## Student Activity

### Materials

- Microscopes
- Slides of TS leaf showing stomata
- Small 'pots' to stand on an electronic balance.

### Procedure

Observe the TS of the leaf for views of the stomata in section.

Place a pot of water on a digital balance and record the loss of mass by evaporation under normal room conditions.

Repeat with fan and/or hair dryer with warm air, and try to record any differences in the rate of water loss by evaporation.

### Set work

Write a paragraph on your observations of the rate of evaporation under different conditions.

Notes:

### 3.3

## Transport in Multicellular Plants

### Learning Outcomes - (L)

Experimental investigation of factors which affect transpiration rate

### Topic Guide

Session:

### Check List

- ▼ Transpiration can be measured using a potometer. The principle of which, is that as the water evaporates from the leaves of the shoot, water is moved up the shoot by the cohesive pull of the transpiration stream, and air (bubble) is drawn along the capillary tube at the same rate - thus giving a measure of the rate of transpiration. The time taken for the air to travel a certain distance, or the distance travelled in a certain time, can be recorded and the rate of transpiration calculated.
- ▼ Actually it is the rate of water uptake that is being measured, which under these experimental conditions is not the same as the transpiration rate. In this experiment the cross sectional area of the cut shoot is not as large as the equivalent area of root hairs that would normally supply the leaves, therefore the rate of uptake is less than the rate of transpiration.
- ▼ The potometer is filled by immersing it totally in water, preferably freshly boiled and cooled water which has no air bubbles.
- ▼ The shoot to be used should be cut from the plant and fitted into the potometer under water, to prevent any air bubbles entering the xylem elements.
- ▼ All joints should be well vaselined to seal leaks
- ▼ If the calibration on the capillary tube is in millimetres, and the diameter and hence the radius of the tube is known, then the volume of water taken up can be calculated using the formula:  
$$\pi r^2 \times \text{distance travelled by bubble} = \text{volume of water uptake}$$
- ▼ Sometimes the calibrations are already in units of volume, for example mm<sup>3</sup> or cm<sup>3</sup> (ml).

## Student Activity

### Materials

- Practical Work Sheet 14:  
**Factors affecting the rate of transpiration using the potometer**
- Supplementary Practical Work Sheet 15:  
**Loss of mass from leaves under different conditions**

### Procedure

Follow the procedure set out in the Practical Work Sheets.

Name other factors which affect the rate of water uptake from the soil e.g the active uptake of inorganic ions by root hair cells giving rise to an osmotic gradient.

List the variables which might affect the rate of transpiration: temperature, humidity, air movement, light. What is the relationship between light and stomatal opening?

### Set work

List the similarities and differences between transpiration in a plant and sweating in a human.

Notes:



### 3.3

## Transport in Multicellular Plants

### Learning Outcomes (LO)

Distribution of xylem and phloem tissue in roots, stems and leaves of dicotyledonous plants

### Topic Guide

Session: \_\_\_\_\_

### Check List

- ▼ Dicotyledonous plants have a distinctive pattern of distribution of xylem and phloem tissue in roots stems and leaves.
- ▼ In comparison with monocotyledonous plants (grasses, bulb plants etc) which have a different pattern.
- ▼ Pattern of distribution in dicotyledons can be related to stresses exerted on the particular part.
- ▼ Xylem and fibres surrounding the vascular bundle contain the supporting material lignin.
- ▼ Non-woody stems must resist bending in the wind therefore xylem and associated lignified tissues found in circle towards outside edge of stem where compressive and tensile forces are greatest.
- ▼ Roots must resist pulling as the stem bends therefore root xylem found as a central core to resist pulling strains.
- ▼ Some water plant stems have to resist pulling strains and xylem found in centre of these.
- ▼ Xylem in mid rib and veins supports leaves.

## Student Activity

### Materials

- Microscopes and calibrated eye piece graticules.
- Prepared slides of TS stem, root and leaf showing vascular tissues
- OHT Distribution of vascular tissues in stem root and leaf
- OHT Xylem and phloem TS and LS

### Procedure

Set up microscopes with TS stem on low power.  
□ OHT shows the following: vascular bundle, regions of xylem, phloem. Focus on each tissue in turn using the high power.

□ OHT illustrates the structure of xylem and phloem cells.

Describe and compare the xylem and phloem cells as seen under high power. Note the colour of the stain (red indicates the presence of lignin, only found in secondary cells walls). Measure the thickness of the cell walls. Comment on the relative diameters of the phloem sieve tubes and companion cells, xylem vessels and tracheids. Why should there be more water transporting tissue than sugar transporting tissue?

Examine the slides of root and leaf sections. Use OHT to help locate the xylem and phloem.

Make sketches to compare the distribution of xylem and phloem tissues in roots, stems and leaves. Suggest a reason for the difference in distribution between roots and stems. Consider the different mechanical stresses on roots and stems.

### Set work

Write ten lines on each to describe how:

a) xylem and b) phloem tissues and are adapted for their particular functions.

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### 3.3

## Transport in Multicellular Plants

### Learning Outcomes (LO11)

Structure and function of xylem vessels, sieve tube elements and companion cells

### Topic Guide

Session:

### Check List

- ▼ Structure of vessels: lignification, pits, empty lumen, reduction of cross walls, up to a metre long.
- ▼ Diameters of vessels ranging from 20 - 600  $\mu\text{m}$ .
- ▼ Little resistance offered to flow of water in transpiration stream.
- ▼ Note that tallest trees in the world are conifers which lack vessels only having tracheids.
- ▼ Contents of vessels under negative pressure (tension) as a result of transpiration stream.
- ▼ Sieve tube elements in phloem have living contents, sieve tube plates, but no nuclei, only companion cells have nuclei.
- ▼ Only sieve tube elements with streaming cytoplasm are functional, in older elements sieve plates become blocked with callose rendering them non-functional.
- ▼ Contents of sieve tube elements (mainly sucrose in solution) are under positive pressure.

## Student Activity

### Materials

- Microscopes
- Matches teased and stained in phloroglucinol and HCl
- Practical Work Sheet 13:  
**The observation of xylem vessels, sieve tube elements and companion cells using the light microscope**
- ☐ OHT - Structure of vessels in xylem
- ☐ OHT - Structure of sieve tube elements and companion cells in phloem

### Procedure

Observe teased matches stained in phloroglucinol and HCl which stains lignin red, for 3D view of xylem elements. Good reminder of role of xylem as wood in everyday life.

Discussion will tend to be dominated by xylem vessels because there is much more to say about the relation of their structure to function.

Presence only in Flowering plants (absence in Gymnosperms could be discussed in relation to xeromorphy and reduced transpiration rates of the 'evergreen' Gymnosperms, although NB Larch a deciduous Gymnosperm).

Note two key points about nature of lignin: waterproof, avoiding absorption and keeping water in the lumen;  
strong to withstand huge negative pressures 'suction' generated by the transpiration stream, with

regard to which could demonstrate or simply refer to collapsing a paper 'straw' by sucking fluid up and refer to the decrease in diameter of tree trunks under conditions of high transpiration.

The necessity of a continuous column of water for cohesion should be related to the problems of:

air bubbles, as a result of columns of water breaking under tension or wind movements (can be detected audibly with sensitive equipment), or freezing forcing air out of solution in the xylem;

presence of pits to allow for a continuous system of water to bypass any such air bubbles and breaks in the columns of water

Examination of some cross sections of woody stems is interesting, and can demonstrate:

annual rings of Spring vessel production.

the distinction between the water transporting younger 'sap wood', and the the older 'heart wood' consigned to pure support and storage of waste materials. The 'sap wood' changes into 'heart wood' at different rates in different species, but some may not show this distinction at all e.g. Willow.

Position of phloem outside the expanding cylinder of xylem, and its unthickened cellulose cell walls, mean that secondary phloem is continually being stretched and destroyed in woody parts, and does not accumulate like the xylem.

### Set work

Explain in terms of the movement of water through the plant why vessels with a larger cross section are mainly produced in the spring in temperate climates like ours.

### 3.3

## Transport in Multicellular Plants

Examining Outcomes (4)

Movement of water between plant cells and between them and their environment in terms of water potential

### Topic Guide

Session:

### Check List

- ▼ The cell membrane is partially permeable allowing water molecules to pass through it but not most solute molecules.
- ▼ The cell wall is freely permeable.
- ▼ As partially permeable membrane prevents free diffusion of solute molecules, water moves by osmosis down a water potential gradient.
- ▼ Water potential is a measure of the tendency to gain or lose water in relation to pure water. If the fluid is pure water there is no movement and the water potential is zero.
- ▼ The presence of solutes slow the movement of water molecules giving any solution a negative water potential at normal pressures.
- ▼ Water will move from regions of high to low water potential (from less negative to more negative values).
- ▼ If fluid outside a plant cell is more dilute than contents, water enters by endosmosis and the cell contents expand until this force is counterbalanced by the force exerted by the stretched cell wall. At this equilibrium point the cell is described as fully turgid. In a well watered plant, the turgid cells exert pressure on each other making the whole structure rigid.
- ▼ Loss of water causes a loss in turgor resulting in wilting of leaves.
- ▼ If the water potential of the cell contents is greater than that of the surrounding solution, water moves out of the cell by exosmosis and the membrane shrinks away from the cell wall. Cells in this state are said to be plasmolysed. In natural conditions, a plant would die before its cells reached the state of plasmolysis.
- ▼ All plasmolysed cells are flaccid but not all flaccid cells are plasmolysed.

## Student Activity

### Materials

- Microscopes
- Red onions/Rhubarb epidermis and a sharp kitchen knife
- Solution containing 5g. per litre sucrose (labelled)
- Distilled water (labelled)
- For each student: one scalpel, 2 microscope slides and coverslips
- OHT Diagrams of (i) turgid and (ii) plasmolysed cells

### Procedure

Prepare two small pieces of the one cell thick membrane separating the onion leaves/Rhubarb epidermis and place them on separate microscope slide. To the first add a drop of distilled water followed by a coverslip. Repeat with the second, using a drop of sugar solution. remove any excess

fluid with tissue paper, then examine under the high power lens of the microscope. Make notes and diagrams to compare the appearance of the two slides.

Look at the OHT and relate these diagrams to the actual appearance of their slides. Consider turgor and plasmolysis in terms of water potential and pressure potential without using formulae and symbols.

In the case of plasmolysed cells note shape of withdrawing membrane which can reveal position of plasmodesmata by remaining pulled out in these positions.

Note that solutes (including sucrose) can slowly diffuse through the cell surface membrane, so that after a while in the same sucrose solution plasmolysed cells may recover from plasmolysis.

### Set work

Briefly describe the problems of water uptake experienced by estuarine plants in terms of water potential.

### 3.3

## Transport in Multicellular Plants

### Learning Outcomes (LO)

Pathway and mechanism of water transport from roots to leaves

### Topic Guide

Session:

### Check List

- ▼ Transpiration in the leaves generates the major force for the upward movement of water in the transpiration stream.
- ▼ Root hairs actively take up inorganic ions and water follows passively down a water potential gradient generating a root pressure.
- ▼ Root pressure can only account for a rise of a few metres but could be important before leaves are fully open in the spring in temperate climates.
- ▼ Three main pathways of water movement across the root, vacuolar pathway, cytoplasmic pathway, and apoplastic pathway.
- ▼ These three pathways above being in order of decreasing resistance and increasing volume.
- ▼ Once in xylem, capillarity aids rise but main force is generated by transpiration at the leaves.
- ▼ Cohesion prevents breakage of continuous water column as it is pulled up under negative pressure (tension).
- ▼ Adhesion of water to the walls of the xylem supports the water column.
- ▼ Breakages (air bubbles) caused by frost and/or wind damage can be by-passed via pits in lateral walls of xylem tracheids and vessels.
- ▼ Endodermis passage cells only point where water must pass through cell surface membranes on its passage through the plant.

## Student Activity

### Materials

- 2 microscope slides separated at one long edge by a half match stick and bound together by a rubber band (one per student)
- 2 petri dish with 2mm depth of methylene blue solution (one per two students)

### Procedure

Stand one end of the microscope slides in the methylene blue solution and watch as the liquid moves up between the slides. Make a sketch to illustrate the final appearance of the liquid. Take the slides out of the petri dish and note how the liquid remains between the slides.

Make brief notes to explain how water molecules tend to adhere to surfaces and to each other. Relate this to narrow tubes (the xylem vessels) Water will move up by capillarity as it adheres to the inner surfaces of the xylem walls.

### Set work

Write a paragraph explaining the terms sap wood and heart wood.

Notes:

### 3.3

## Transport in Multicellular Plants

### Learning Objectives (LO 17)

Translocation of assimilates especially sucrose

### Topic Guide

Session: \_\_\_\_\_

\_\_\_\_\_

### Check List

- ▼ Translocation of assimilates (organic substances synthesised in the plant by photosynthesis) e.g. sugars, amino acids, hormones, nucleic acids etc. occurs in the phloem tissue.
- ▼ Organic materials move from an area of manufacture (source) to an area where they are used (sink). Sucrose thus moves from the leaves (sources) to actively growing and respiring regions such as the roots, flowers, and new buds (sinks).
- ▼ Phloem tissue (unlike most of the Xylem) is composed of living cells and elements.
- ▼ Mechanism of movement still not fully understood.
- ▼ Mass flow mechanism postulates high hydrostatic pressure in sources and low in sinks.
- ▼ Contents are under positive pressure.
- ▼ Movement occurs in both directions.
- ▼ Movement of assimilates is stopped if the phloem is poisoned with a respiratory inhibitor, exposed to high or low temperatures i.e. translocation is an active process, only occurring in those sieve tube elements showing cytoplasmic streaming.

## Student Activity

Notes: \_\_\_\_\_

### Materials

- Two similar woody potted plants
- OHT Autoradiographs of ringing experiment.

### Procedure

Carefully remove a 5mm ring of all the tissue external to the xylem in the stem of one of the plants.

Set both plants aside under ideal conditions for regular daily observation.

Keep a record of your observations of the plants and compare them with the diagrammatic representations of ringing experiments.

- OHT Autoradiographs of ringing experiment can be used to anticipate results

### Set work

Write a paragraph explaining the origin of the sugary film found on pavements and parked cars under trees in the summer months.

### 3.3

## Transport in Multicellular Plants

### Learning Outcomes – (L)

Adaptation of leaves of xerophytes to reduce water loss by transpiration

### Topic Guide

Session:

### Check List

- ▼ Thickened waterproof cuticle reduces water loss through the surface of the leaf, especially on the upper surface of the leaf which is most exposed to air currents and heat absorption from sunlight.
- ▼ Surface of the leaf may be 'hairy' (not true hairs) which protect the stomata from air currents.
- ▼ Stomata can be sunken in pits and grooves, which protects them from air currents, e.g. on pine 'needles'.
- ▼ Stomata can be reduced in number, especially on the upper surface of the leaves, where the exposure to the heat of the sun and air currents is the greatest, indeed some e.g. laurel, have no stomata on the upper surface.
- ▼ Leaves can have a reduced surface area, which also reduces the number of stomata, e.g. pine 'needles'; and gorse and cacti where the leaves are reduced to spines.
- ▼ Leaf folding or rolling reduces water loss through the stomata by protecting them from air currents, and enclosing them in a zone of high humidity, e.g. *Ammophila* (sand dune grass).
- ▼ Leaves can be succulent, with tissues where water can be stored for periods of drought, e.g. Cacti.
- ▼ Cells of the leaves have mucilage and can withstand dehydration for longer periods than those of non-xerophytes (mesophytes).
- ▼ Leaf fall stops transpiration. Deciduous plants lose their leaves with the onset of winter in temperate regions, when the low temperatures inhibit water uptake by the roots.

## Student Activity

### Materials

- Assorted plants and parts of plants showing a range of xerophytic adaptations e.g. cactus with spines, succulent with fleshy leaves, pine needles, holly leaves, marram grass, plus one mesophyte e.g. *Pelargonium*.
- Microscopes and slides
- Two leaves per student (one xerophyte e.g. holly and one mesophyte, e.g. *Pelargonium*) coated on their under surface with a layer of clear nail varnish.

### Procedure

Compare the numbers and distribution of stomata on a xerophytic leaf e.g. holly and a mesophytic leaf. Carefully peel off the layer of nail varnish that has been painted on to the lower leaf surfaces of the two plant types and mount a small piece on a microscope slide. Examine the imprint of the epidermal surface and identify the guard cells and stomata. Count how many stomata occur in the field of view, then repeat this count on different parts of

the slide. Record the average, then repeat using the other leaf (on the same power of magnification). Compare the numbers of stomata on the two leaves.

Note that not all of the xerophytic adaptations are limited to plants living in hot dry climates. Other important groups of plants show xerophytic (water stress) modifications e.g.

Plants which shed their leaves all year round (evergreens) and which must survive long frozen winters (e.g. conifers)

Plants adapted to salty environments (halophytes) e.g. salt marsh plants

Wet acid heath plants where water uptake is restricted by xerophytic modifications to avoid toxic levels of iron uptake.

### Set work

Tabulate your results of stomatal counts and draw conclusions on the distribution of stomata in relation to water loss.

# Biology

## Exam Style Questions

- 1 - Biology Foundation**
- 2 - Human Health & Disease**
- 3 - Transport**

**FELTHAM PRESS**

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# Examination Style Question Papers

## Biology

### I - Biology Foundation Year Set I

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Time allowed 1 hour 30 minutes

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#### Instructions:

- Answer all the questions in the spaces provided.

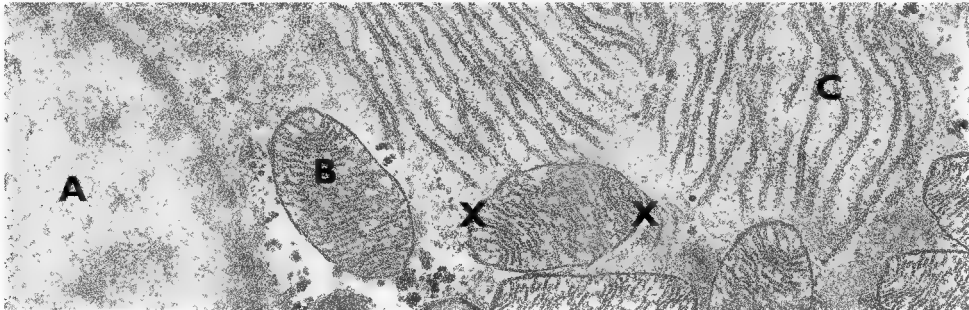
#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- about 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.



## Question 1

The picture below shows part of a cell as seen under an electron microscope at a magnification of  $\times 30\,000$ , with all parts shown accurately to scale.

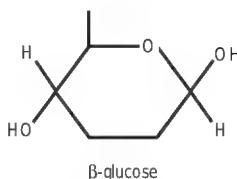
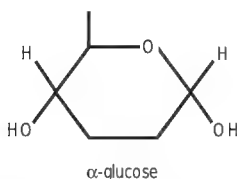


- a) Identify structures A to C.
- A** \_\_\_\_\_
- B** \_\_\_\_\_
- C** \_\_\_\_\_ (3)
- b) Describe two ways in which a bacterial cell differs from the cell shown above.
- i)** \_\_\_\_\_ (1)
- ii)** \_\_\_\_\_ (1)
- c) Calculate the actual size of structure B as measured between the two points marked X. Show your workings.
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_ (3)
- d) i) Name a structure in the drawing that is not visible even under the best light microscope?
- \_\_\_\_\_ (1)
- ii) Explain the meaning of and distinguish between resolution and magnification with reference to light microscopy and electron microscopy. (In this question, 1 mark is available for the quality of written communication)
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_ (7)

**Total 16**

## Question 2

- a) The structure of alpha glucose and beta glucose is shown below:



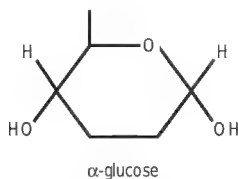
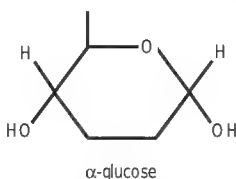
- i) The short-hand convention used in drawing organic molecules in this way omits the carbon atoms. Indicate on one of the diagrams above where the 6 carbon atoms of glucose are to be found.

\_\_\_\_\_ (1)

- ii) Describe how the two molecules shown differ in structure.

\_\_\_\_\_ (1)

- b) Two alpha glucose molecules are shown below:



- i) Indicate on the diagram how the disaccharide maltose would be formed. (1)

- ii) Name the type of reaction that you have indicated on the diagram.

\_\_\_\_\_ (1)

- iii) Name the chemical bond formed in this way.

\_\_\_\_\_ (1)

- iv) Name and describe the type of reaction that would result in the two alpha glucose molecules being regained from the maltose molecule.

\_\_\_\_\_  
\_\_\_\_\_ (2)

- c) Describe how you would test for, and deduce the presence of glucose in a solution of unknown composition.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**Total 10**

### Question 3

- a) i) Give a definition of the term catalyst.

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(2)

- ii) Name an enzyme and the reaction that it catalyses.

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---

(1)

- b) i) Describe with the use of an appropriate example what is meant by the term 'enzyme specificity'

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---

---

(2)

- ii) It is a common mistake to speak of enzymes being 'killed' by, for example, extremes of pH. Explain why this is inaccurate and give the preferred term which should be used.

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---

(3)

- c) Describe how the specificity of an enzyme, and the fact that enzyme activity is disrupted by extremes of pH and high temperatures, can be explained in terms of the structure of enzymes.

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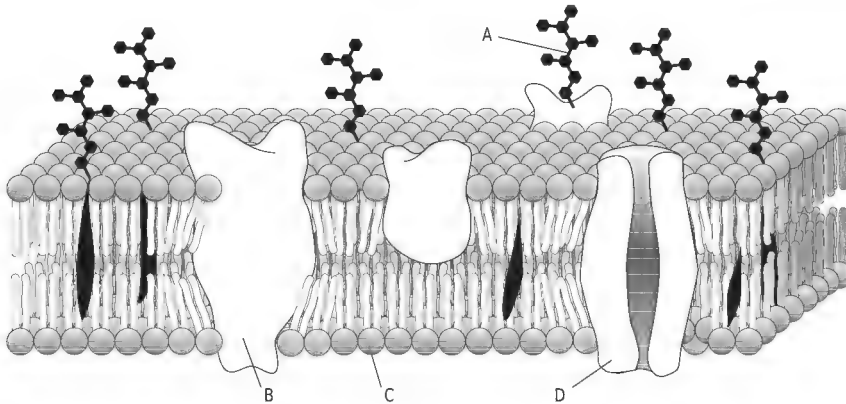
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(3)

**Total 11**

#### Question 4

- a) Label the structures A, B, C, and D on the simplified diagram of the cell surface membrane shown below



- b) Describe why phospholipids always form bilayers in aqueous systems. (4)

\_\_\_\_\_  
\_\_\_\_\_ (2)

- c) Describe the roles of the following components of the cell surface membrane.

i) cholesterol  
\_\_\_\_\_ (1)

ii) glycoproteins  
\_\_\_\_\_ (1)

iii) carrier proteins  
\_\_\_\_\_  
\_\_\_\_\_ (1)

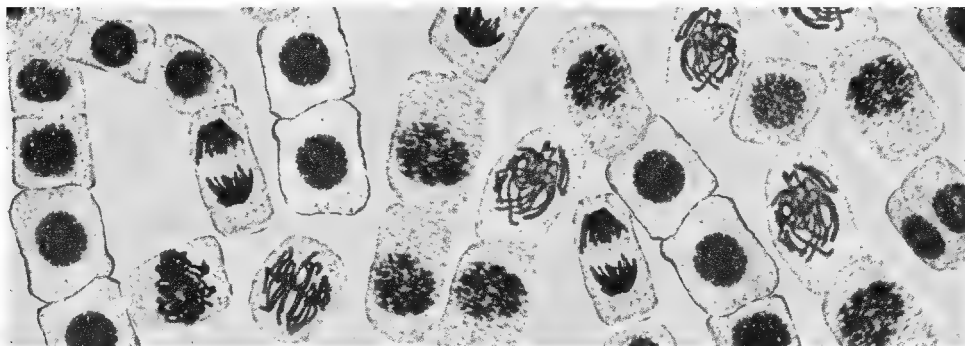
- d) Give a brief description of the transport of substances through the cell surface membrane by endocytosis and exocytosis.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

**Total 13**

### Question 5

Study the illustration below of stained cells from a squashed root tip of a plant, showing various stages of mitosis, and answer the questions that follow.



a) i) Indicate with an X on the illustration a cell which is showing the separation of chromatids. (1)

ii) Indicate with a Y on the illustration a cell which is showing the chromosomes lining up on the equator of the nuclear spindle. (1)

iii) Explain why the specimen was squashed and not sectioned.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

b) Explain why plant root tips are a good source of cells undergoing mitosis.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

c) Give a definition for each of the following terms:

i) diploid chromosome number;

\_\_\_\_\_ (1)

ii) haploid chromosome number;

\_\_\_\_\_ (1)

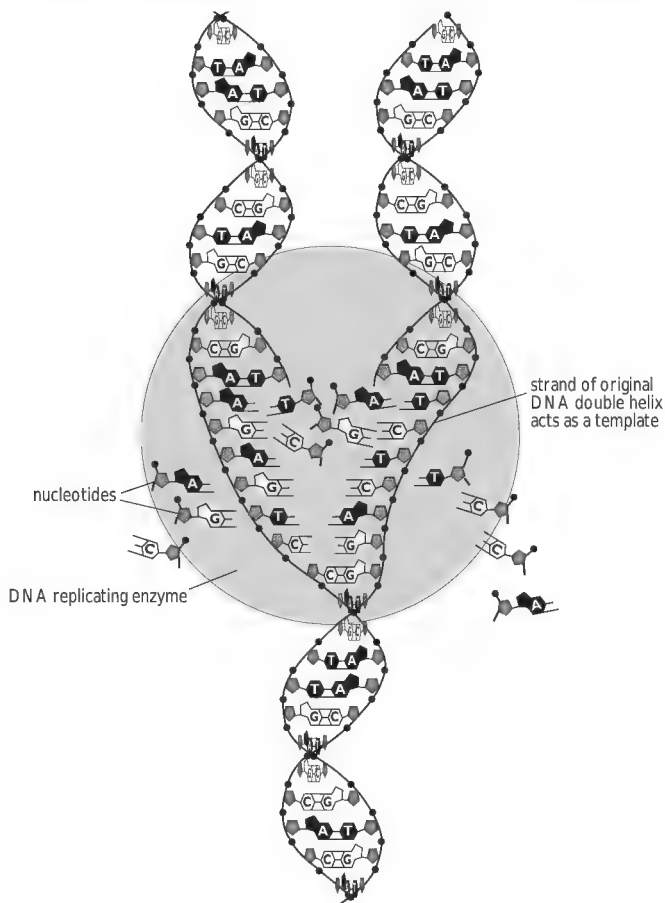
d) Briefly explain gamete formation and fertilisation using the terms diploid chromosome number and haploid chromosome number.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**Total 14**

## Question 6

Study the diagram of replicating DNA shown below and then answer the questions that follow.



a) On the diagram:

- i) label the two new strands of DNA; (1)
- ii) mark with an 'X' the position of a pair of complementary bases; (1)
- iii) indicate with an arrow the direction in which the new strands of DNA are being formed; (1)

*Question continued...*

---

**b)** With reference to the diagram:

**i)** describe what is meant by semi-conservative replication;

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**ii)** name an enzyme involved in catalysing the chemical reactions of DNA replication.

\_\_\_\_\_ (1)

**c) i)** In eukaryotic cells nuclear DNA does not leave the nucleus, describe where else in a plant cell DNA is found.

\_\_\_\_\_  
\_\_\_\_\_ (2)

**ii)** Describe the distribution of DNA in a prokaryotic cell.

\_\_\_\_\_  
\_\_\_\_\_ (2)

**Total 11**

### Question 7

- a)** Give a named example of each of the following from one named natural habitat:

**i) a photosynthetic producer;**

---

(1)

**ii)** a primary consumer;

---

(1)

- iii) a secondary consumer:

(1)

- b) Describe the ways in which energy is lost between the photosynthetic producers and the primary consumers.

---

(3)

- c) Materials in an ecosystem undergo perpetual recycling, explain why energy is described as 'flowing through' an ecosystem. (In this question one mark is available for the quality of written communication.)

[illegible]

(9)

**Total 15**



# Assessment Grid

## Biology

### I - Biology Foundation

#### Year Set I

| Specification Section          | Question Number |    |    |    |    |    |    | Total |
|--------------------------------|-----------------|----|----|----|----|----|----|-------|
|                                | 1               | 2  | 3  | 4  | 5  | 6  | 7  |       |
| I.1 Cell Structure             | 16              |    |    |    |    |    |    | 16    |
| I.2 Biological Molecules       |                 | 10 |    |    |    |    |    | 10    |
| I.3 Enzymes                    |                 |    | 11 |    |    |    |    | 11    |
| I.4 Cell Membranes/Transport   |                 |    |    | 13 |    |    |    | 13    |
| I.5 Genetic Control of Protein |                 |    |    |    | 14 |    |    | 14    |
| I.6 Nuclear Division           |                 |    |    |    |    | 11 |    | 11    |
| I.7 Energy and Ecosystems      |                 |    |    |    |    |    | 15 | 15    |

Total 90

| Assessment Objective            | Question Number |   |   |    |   |   |   | Total |
|---------------------------------|-----------------|---|---|----|---|---|---|-------|
|                                 | 1               | 2 | 3 | 4  | 5 | 6 | 7 |       |
| AO1                             |                 |   |   |    |   |   |   |       |
| Knowledge with Understanding    | 13              | 7 | 5 | 11 | 7 | 8 | 6 | 57    |
| AO2                             |                 |   |   |    |   |   |   |       |
| Application/Analysis/Evaluation | 3               | 3 | 6 | 2  | 7 | 3 | 9 | 33    |

Total 90

# Mark Schemes for Question Papers

## Biology

### I - Biology Foundation Year Set I

#### Instructions

; 1 mark / = alternative response

#### Question I

The picture below shows part of a cell as seen under an electron microscope at a magnification of  $\times 30\,000$ , with all parts shown accurately to scale.

- a) Identify structures A to C.  
A nucleus;  
B mitochondrion;  
C rough or granular endoplasmic reticulum; (3)
- b) Describe two ways in which a bacterial cell differs from the cell shown above.  
i) & ii) any two from  
bacterium cell has no mitochondria;  
no nucleus;  
no endoplasmic reticulum; (2)
- c) Calculate the actual size of structure C as measured between the two points marked X.  
Show your workings.  
distance between points x-x = 30 mm;  
magnification =  $\times 30\,000$   
therefore actual size = 25 divided by 30 000;  
= 0.001 mm / 1.0  $\mu\text{m}$ ; (3)
- d) i) Name a structure in the drawing that is not visible even under the best light microscope?  
ribosomes (1)
- ii) Explain the meaning of and distinguish between resolution and magnification with reference to light microscopy and electron microscopy.  
Quality of written communication assessed in this answer.  
resolution is the ability to distinguish between adjacent points;  
allows detail to be differentiated;  
determines the amount of information that can be gained;  
in light microscopy (LM) determined by the wavelength of light;  
in electron microscopy (EM) determined by the 'wavelength' of electrons;  
magnification is enlargement;  
increasing magnification reveals no extra detail if resolution is poor;  
maximum useful magnification with LM about 1500;  
maximum useful magnification with EM about 250 000; (6)
- Q - legible text with accurate spelling, punctuation and grammar; (1)

**Total 16**

---

## Question 2

- a) The structure of alpha glucose and beta glucose is shown below:
- i) The short-hand convention used in drawing organic molecules in this way omits the carbon atoms. Indicate on one of the diagrams above where the 6 carbon atoms of glucose are to be found.  
all 6 carbons accurately marked; (1)
- ii) Describe how the two molecules shown differ in structure.  
positions of OH and H groups on carbon one reversed; (1)
- b) Two alpha glucose molecules are shown below:
- i) Indicate on the diagram how the disaccharide maltose would be formed.  
removal of elements of water correctly indicated; (1)
- ii) Name the type of reaction you have indicated.  
condensation reaction; (1)
- iii) Name the chemical bond formed in this way.  
glycosidic bond (1)
- iv) Name and describe the type of reaction that would result in the two alpha glucose molecules being regained from the maltose molecule.  
hydrolysis reaction;  
elements of water added;  
across the glycosidic bond; (2)
- c) Describe how you would test for, and deduce the presence of glucose in a solution of unknown composition.  
add Benedict's solution;  
boil;  
positive result green, yellow, brick red ppt; (3)

**Total 10**

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### Question 3

- a) i) Give a definition of the term catalyst.  
a substance which speeds up the rate of a reaction;  
without itself being used up;  
both needed for the mark; (2)
- ii) Name an enzyme and the reaction that it catalyses.  
both needed for the mark; (1)
- b) i) Describe with the use of an appropriate example what is meant by the term 'enzyme specificity'  
an enzyme will only catalyse one particular reaction or type of reaction;  
any appropriate example; (2)
- ii) It is a common mistake to speak of enzymes being 'killed' by, for example, extremes of pH.  
Explain why this is inaccurate and give the preferred term which should be used.  
enzymes not living therefore cannot be 'killed';  
lose their ability to act as catalysts;  
preferred term 'denatured'; (3)
- c) Describe how the specificity of an enzyme, and the fact that enzyme activity is disrupted by extremes of pH and high temperatures, can be explained in terms of the structure of enzymes.  
enzymes are proteins with complex three dimensional structures;  
which determines their specificity;  
extremes of pH and high temperatures disrupt the complex three dimensional structure. (3)

**Total 11**

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## Question 4

- a) Label the structures A, B, C, and D on the simplified diagram of the cell surface membrane shown below.
- A** Glycoprotein;
  - B** Transmembrane protein;
  - C** Phospholipid;
  - D** Pore protein; (4)
- b) Describe why phospholipids always form bilayers in aqueous systems.
- phospholipids have hydrophilic and hydrophobic poles;
- hydrophobic poles 'attract' each other; (2)
- c) Describe the roles of the following components of the cell surface membrane.
- i) cholesterol
  - stabilises the lipid bilayer; (1)
  - ii) glycoproteins
  - cell surface recognition / communication; (1)
  - iii) carrier proteins
  - transport of substances into and out of cell; (1)
- c) Give a brief description of the transport of substances through the cell surface membrane by endocytosis and exocytosis.
- endocytosis involves 'ingesting' a volume of the exterior solution;
- enclosing it within a vacuole within the cell;
- exocytosis involves a vacuole / vesicle reaching cell surface membrane from cell interior;
- membrane of vesicle coalesces with cell surface membrane;
- contents secreted to exterior; (4)

**Total 13**

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## Question 5

Study the illustration below of stained cells from a squashed plant root tip, showing various stages of mitosis, and answer the following questions.

- a) i) Indicate with an 'X' on the illustration a cell which is showing the separation of chromatids.  
cell correctly identified (1)
- ii) Indicate with a 'Y' on the illustration a cell which is showing the chromosomes lining up on the equator of the nuclear spindle.  
nucleus correctly identified (1)
- iii) Explain why the specimen was squashed and not sectioned.  
squashing separates out the individual chromosomes;  
in one plane;  
so all can be seen;  
sectioning would only catch parts of chromosomes; (4)
- b) Explain why plant root tips are good source of cells undergoing mitosis.  
growing regions;  
apical meristem just behind tip;  
produce nuclei by mitosis in all directions; (3)
- c) Give a definition for each of the following terms:
- i) diploid chromosome number;  
having two sets of chromosomes (homologous) / complete set of paired chromosomes; (1)
- ii) haploid chromosome number;  
having one set of chromosomes / only one of each pair of chromosomes; (1)
- d) Briefly explain gamete formation and fertilisation using the terms diploid (chromosome number) and haploid (chromosome number).  
gametes with haploid chromosome number produced by meiosis;  
from germ line cells of parents with diploid chromosome number;  
fertilisation / fusion of haploid gametes forms diploid zygote(s); (3)

**Total 14**

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## Question 6

Study the diagram of replicating DNA and answer the following questions.

- a) On the diagram:
- i) label the two new strands of DNA;
  - ii) mark with an 'X' the position of a pair of complementary bases;
  - iii) indicate with an arrow on the diagram the direction in which the new strands of DNA are being formed; (3)
- b) With reference to the diagram:
- i) describe what is meant by semi-conservative replication;  
each daughter DNA double helix;  
has conserved one strand of the original DNA double helix;  
has one new strand (3)
  - ii) Name an enzyme involved in catalysing the chemical reactions of DNA replication.  
DNA polymerase; (1)
- c) i) In eukaryotic cells nuclear DNA does not leave the nucleus, describe where else in a plant cell DNA is found.  
mitochondria;  
chloroplasts; (2)
- ii) Describe the distribution of DNA in a prokaryotic cell.  
strand of 'chromosomal' DNA;  
plasmids / rings of DNA; (2)

**Total 11**

---

## Question 7

- a) Give a named example of each of the following from one named natural habitat:
- i) a photosynthetic producer;  
any green plant; (1)
  - ii) a primary consumer;  
allow only primary consumer which would feed on first named plant; (1)
  - iii) a secondary consumer;  
allow only secondary consumer which would feed on named primary consumer; (1)
- b) Describe the way in which energy is lost between the photosynthetic producers and the primary consumers.
- inefficiencies of digestion and absorption / lost in faeces;  
energy lost as heat as a result of inefficiencies of respiration particularly muscle contraction;  
energy lost in excretory products; (3)
- c) Quality of written communication assessed in this answer.
- Materials in an ecosystem undergo perpetual recycling, explain why energy is described as 'flowing through' an ecosystem. (In this question one mark is available for the quality of written communication.)
- the only significant source of energy input to ecosystems is solar energy;  
trapped by photosynthetic producers;  
passes through series of inefficient transfers between trophic levels;  
decomposers feed on 'dead' organic matter exploiting this energy;  
with all the same inefficiencies as in the pyramid;  
ultimately all energy within an ecosystem is lost as heat;  
therefore energy flows through from sun's radiant energy to heat; (8)
- Q - clear, well organised using specialist terms; (1)

**Total 15**



# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### 2 - Human Health and Disease Year Set I

*Time allowed 1 hour 30 minutes*

#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- about 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

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## Question I

**a)** Explain, with one example of each, what is meant by the following categories of disease or illness:

**i)** physical,

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(2)

**ii)** mental,

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(2)

**iii)** infectious.

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(2)

**b)** Explain why the division between physical and mental disease is increasingly being seen as unsatisfactory.

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(3)

**b)** Distinguish between health and fitness.

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(3)

**Total 12**

## Question 2

- a) List the main classes of nutrients that are the components of a balanced diet.

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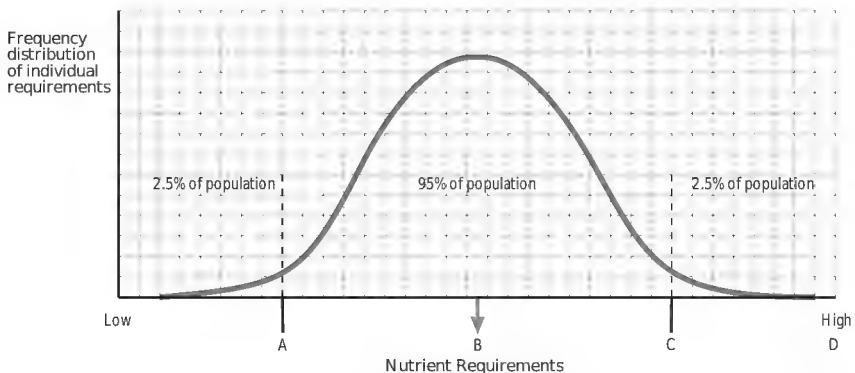
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(3)

- b) Dietary reference values (DRVs) are based on a number of assumptions including that the distribution of requirements in a group of individuals for a nutrient is normally distributed as illustrated in the diagram below.



Match the letters A, B, C, and D with the appropriate description below (letters may be used more than once or not at all).

- i) The point above which the amount of the nutrient under consideration will almost certainly be adequate for most individuals in the group.

---

(1)

- ii) The point below which the amount of the nutrient under consideration will almost certainly be inadequate for most individuals in the group

---

(1)

- iii) The Reference Nutrient Intake (RNI)

---

(1)

- c) Give four reasons why it is not possible for the Dietary reference values (DRVs) for any nutrient to be established with great confidence.

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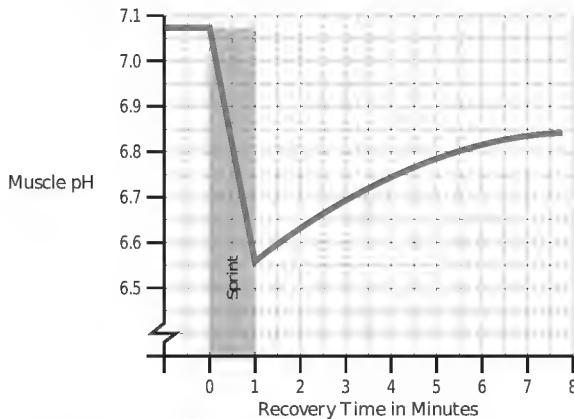
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(4)

**Total 10**

### Question 3

The graph below shows the changes in muscle pH during a 60 second flat out running effort and a recovery period



- a) In terms of anaerobic effort describe why the muscle pH decreases during the sprint.

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(3)

- b) Describe the effect that this drop in muscle pH will have on performance during the 60 second period of effort.

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(3)

- c) In terms of the removal of products of anaerobic respiration explain the recovery of the muscle pH towards what it was before the anaerobic exercise.

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(3)

- d) Describe how aerobic exercise differs from anaerobic exercise in its nature and effects.

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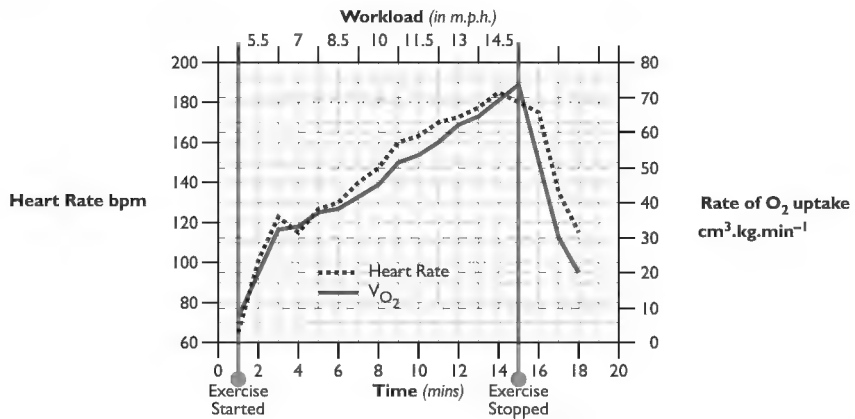
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(4)

**Total 13**

#### Question 4

Study the graph below of heart rate and oxygen uptake of a middle distance runner performing a maximal treadmill test, and answer the following questions.



a) Identify the periods over which:

i) the greatest rate of increase of heart rate and oxygen uptake occurs;

\_\_\_\_\_ (1)

ii) the oxygen uptake continues to increase and the heart rate decreases.

\_\_\_\_\_ (1)

b) For this individual identify the:

i) resting heart rate;

\_\_\_\_\_ (1)

ii) maximum heart rate.

\_\_\_\_\_ (1)

c) Explain why the heart rate and oxygen uptake follow each other so closely throughout this investigation.

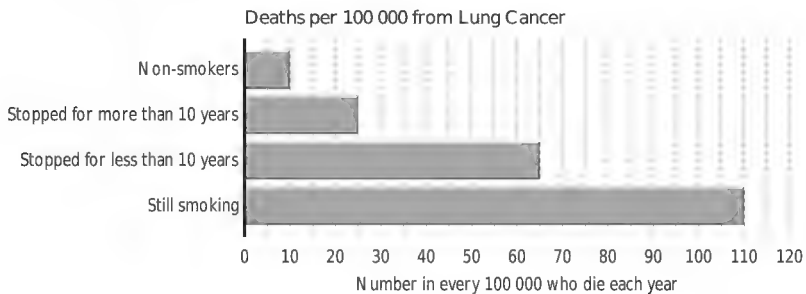
\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_ (3)

Question continued...



## Question 5

Using the data in the diagram below and your own knowledge of smoking and lung cancer, answer the following questions.



- a) Summarise the advantages of stopping smoking in terms of the percentage reduction in risk with passing time.

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(3)

- b) Suggest an explanation for why there is such a high death rate from lung cancer in males between 55-64 years of age.

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(3)

- c) Explain how smoking can harm the unborn child of a non-smoking mother to be.

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(2)

- d) Give an account of the problems involved in demonstrating the link between smoking and lung cancer. (In this question one mark is available for the quality of written communication)

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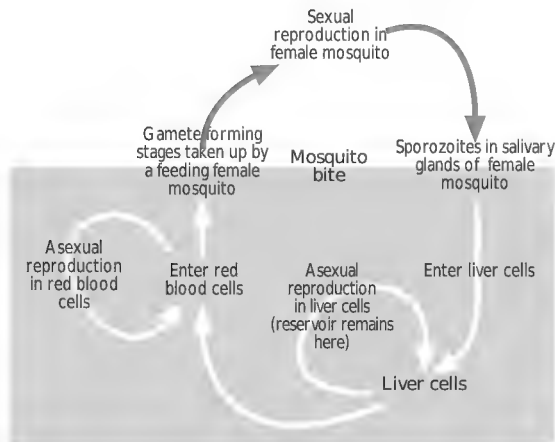
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(7)

**Total 15**

## Question 6

A simplified diagram of the malarial parasite (*Plasmodium*) life cycle is shown below.



- a) i) Explain how the female mosquito injects the malarial parasite into the human host.

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(3)

- ii) What type of organism is the malarial parasite?

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(1)

- iii) Describe the features of the malarial parasite's life cycle that help it to resist the various treatments for sufferers that exist at the present time.

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(3)

- b) Describe the significance of the following factors used in the prevention and control of malaria:

- i) economic

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(2)

- ii) biological

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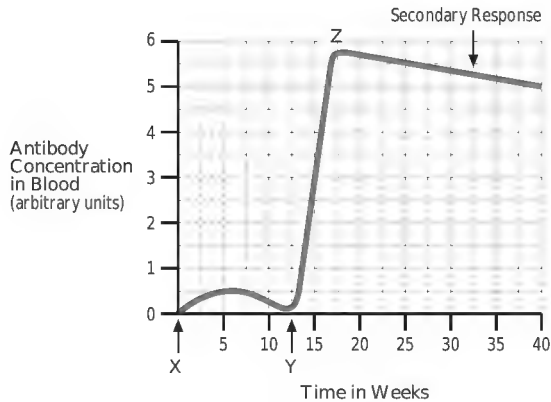
(2)

**Total 11**



## Question 7

The diagram below shows the levels of antibodies in the development of active acquired immunity after exposure to an infectious agent.



a) Match one of the points X, Y, or Z on the diagram with each of the following:

i) the start of the primary response

(1)

ii) the point of second exposure to the infectious agent

(1)

b) With reference to the curve of secondary response in the diagram:

i) explain how subsequent exposures to the disease further boost immunity.

(3)

ii) Describe the relationship between the curve of secondary response in the diagram above and that for the active acquired immunity by vaccination with a booster.

(3)

Question continued...

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**c)** Describe three types of vaccine

**i)** \_\_\_\_\_ (1)  
\_\_\_\_\_

**ii)** \_\_\_\_\_ (1)  
\_\_\_\_\_

**iii)** \_\_\_\_\_ (1)  
\_\_\_\_\_

**d)** Describe two ways in which natural passive immunity may be acquired

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

**Total 15**

## Assessment Grid Biology

### 2: Human Health and Disease

#### Year Set I

|                               | Question Number |    |    |    |    |    |    |   |   |       |
|-------------------------------|-----------------|----|----|----|----|----|----|---|---|-------|
| Specification Section         | 1               | 2  | 3  | 4  | 5  | 6  | 7  | 8 | 9 | Total |
| 2.1 Health and Disease        | 12              |    |    |    |    |    |    |   |   | 12    |
| 2.2 Diet                      |                 | 10 |    |    |    |    |    |   |   | 10    |
| 2.3 Gas Exchange and Exercise |                 |    | 13 | 14 |    |    |    |   |   | 27    |
| 2.4 Smoking and Disease       |                 |    |    |    | 15 |    |    |   |   | 15    |
| 2.5 Infectious Diseases       |                 |    |    |    |    | 11 |    |   |   | 11    |
| 2.6 Immunity                  |                 |    |    |    |    |    | 15 |   |   | 15    |

Total 90

|                                 | Question Number |   |    |    |    |   |   |       |
|---------------------------------|-----------------|---|----|----|----|---|---|-------|
| Assessment Objective            | 1               | 2 | 3  | 4  | 5  | 6 | 7 | Total |
| AO1                             |                 |   |    |    |    |   |   |       |
| Knowledge with Understanding    | 6               | 7 | 10 | 3  | 12 | 7 | 9 | 54    |
| AO2                             |                 |   |    |    |    |   |   |       |
| Application/Analysis/Evaluation | 6               | 3 | 3  | 11 | 3  | 4 | 6 | 36    |

Total 90

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# Mark Schemes for Question Paper

## Biology

### 2 - Human Health and Disease

#### Year Set I

#### Instructions

; = 1 mark    / = alternative response

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#### Question I

- a) Explain, with one example of each, what is meant by the following categories of disease or illness:
- i) physical,  
having manifest physical symptoms with a physical cause;  
malaria;  
diabetes (2)
  - ii) mental,  
of psychological origin with no physical sign of brain disorder;  
depression; (2)
  - iii) infectious,  
caused by a transferable microorganism or particle;  
influenza; (2)
- b) Explain why the division between physical and mental disease is increasingly being seen as unsatisfactory.  
increasingly 'mental illness' shown to be caused by imbalance in chemical neurotransmitters;  
and their receptor sites;  
which is as physical as the cause of many 'physical' diseases e.g. diabetes; (3)
- c) Distinguish between health and fitness.  
possible to be healthy and unfit;  
and fit but unhealthy;  
e.g. sportsmen with inherited heart conditions; (3)

**Total 12**

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## Question 2

- a) List the main classes of nutrients that are the components of a balanced diet.
- carbohydrates;
  - fats;
  - proteins;
  - vitamins;
  - inorganic ions / minerals;
  - (water);
  - (roughage / fibre);
- (3)
- b) Dietary reference values (DRVs) are based on a number of assumptions including that the distribution of requirements in a group of individuals for a nutrient is normally distributed as illustrated in the diagram below.
- Match the letters A, B, C , and D with an appropriate description below (letters may be used more than once or not at all.
- i) The point above which the amount of the nutrient under consideration will almost certainly be adequate = C (1)
- ii) The point below which the amount of the nutrient under consideration will almost certainly be inadequate for most individuals in the group = A (1)
- iii) The Reference Nutrient Intake (RNI) = C (1)
- c) Give four reasons why it is not possible for the Dietary reference values (DRVs) for any nutrient to be established with great confidence.
- based on individual's reports of their food intake;
  - which are inherently inaccurate;
  - food composition tables from which nutrient intake is determined from dietary records are themselves imperfect;
  - uncertainties in establishing the status of an individual for that nutrient;
  - individuals vary tremendously in their requirements;
- (4)

**Total 10**

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### Question 3

The graph below shows the changes in muscle pH during a 60 second flat out running effort and a recovery period

- a) In terms of anaerobic effort describe why the muscle pH decreases during the sprint.  
in absence of sufficient oxygen anaerobic pathways operate;  
resulting in production of lactic acid  
which dissociates into lactate and hydrogen ions;  
pH a measure of hydrogen ion concentration; (3)
- b) Describe the effect that this drop in muscle pH will have on performance during the 60 second period of effort.  
inhibits muscle contraction;  
by inhibiting enzyme activity;  
muscle contraction slows and stops;  
perception of pain reduces effort;  
performance drops; (3)
- c) In terms of the removal of products of anaerobic respiration explain the recovery of the muscle pH back towards that before the anaerobic exercise.  
lactate removed by the blood circulation;  
and the lymphatic system;  
to be oxidised elsewhere eg heart muscle;  
pH raised by exhalation of carbon dioxide in the lungs;  
excretion by kidneys; (3)
- d) Describe how aerobic exercise differs from anaerobic exercise in its nature and effects.  
aerobic exercise does not develop an oxygen deficit / debt;  
oxygen supply matches demand by muscles;  
no build up lactate / lactic acid;  
steady / rhythmic endurance exercise;  
develops aerobic endurance fitness; (4)

**Total 13**

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## Question 4

Study the graph below of heart rate and oxygen uptake of a middle distance runner performing a maximal treadmill test, and answer the following questions.

- a) Identify the periods over which:
- i) the greatest rate of increase of heart rate and oxygen uptake occurs;  
1 - 2 minutes / first minute of exercise (1)
  - ii) the oxygen uptake continues to increase and the heart rate decreases.  
14 - 15 minutes / 13 - 14 minutes after the start of exercise (1)
- b) For this individual identify the
- i) resting heart rate;  
65 - 70 bpm (1)
  - ii) maximum heart rate.  
180 - 185 bpm (1)
- c) Explain why the heart rate and oxygen uptake follow each other so closely throughout this investigation.
- tissues (muscles) demand oxygen for aerobic respiration;  
demand for oxygen met by increase in blood supply;  
increase in blood supply achieved by increase in cardiac output which involves an increase in heart rate; (3)
- d) Interpret the overall shape of the curves in terms of what is occurring within the athlete's body during this investigation.
- at start of exercise rapid demand for extra oxygen by muscles;  
heart rate and oxygen uptake increase accordingly;  
after 3 minutes of effort rates of both slow as intensity cannot be maintained;  
steady increase to maximum values;  
oxygen uptake continues to rise after heart rate starts to fall as a result of continuing high rate of extraction by maximally working muscles;  
point of exhaustion reached and exercise stopped;  
complication of strength of motivation of athlete  
slow decrease after stopping as a result of post exercise oxygen consumption (EPOC)  
measurements terminated before full recovery; (6)
- Q - legible text with accurate spelling, punctuation and grammar; (1)

**Total 14**

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## Question 5

Using the data presented below and your own knowledge on smoking and lung cancer, answer the following questions.

- a) Summarise the advantages of stopping smoking in terms of the percentage reduction in risk with passing time.  
47% / 44% reduction in risk after stopping for 10 years;  
86% / 79% reduction in risk after stopping for more than 10 years;  
(first figures of pairs allow for 10 non-smoking fatalities per 100 000)  
risk never returns to normal; (3)
- b) Suggest an explanation for why there is such a high death rate from lung cancer in males between 55-64 years of age.  
length of time smoking increases risk;  
40 to 50 years ago smoking widely accepted;  
risks only beginning to be understood then;  
females smoked less than males in past;  
cancer primarily a disease of old age; (3)
- c) Explain how smoking can harm the unborn child of a non-smoking mother to be.  
passive smoking by mother;  
nicotine and carcinogens into bloodstream of mother;  
cross placenta and damage foetus; (2)
- d) Give an account of the problems involved in demonstrating the link between smoking and lung cancer.  
correlation does not prove cause and effect;  
minority of smokers (35%-50%) die of lung cancer;  
multi-factorial causes of cancer;  
including inherited propensity;  
many other atmospheric pollutants implicated;  
epidemiological studies required with large numbers for statistical significance;  
over long periods of time / longitudinal studies;  
difficult to ensure accurate answers from smokers about their habit;  
animal experiments do not always translate to humans; (6)  
Q - clear, well organised using specialised terms; (1)

**Total 15**



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## Question 6

A simplified diagram of the malarial parasite (*Plasmodium*) life cycle is shown below.

- a) i) Explain how the female mosquito injects the malarial parasite into the human host.  
female feeds on human blood;  
injects anti-coagulant saliva into wound;  
thus introducing the malarial parasite into the host; (3)
- ii) What type of organism is the malarial parasite.  
single celled;  
prototistan / protozoan; (1)
- iii) Describe the features of the malarial parasite's life cycle that help it resist the various treatments that exist for sufferers at the present  
intracellular in liver cells acts as a reservoir of infection;  
reservoirs of infection in liver cells protected from immune system;  
and drugs;  
result in waves of emergence into blood stream long after initial infection;  
intracellular in red blood cells; (3)
- b) Describe the roles of the following factors in the prevention and control of malaria:
- i) economic  
anti-malarial spraying programmes expensive;  
management of vector and parasite e.g. draining programmes, prophylactics, expensive; (2)
- ii) biological  
knowledge of mosquito life cycle allows attack of vector e.g. introduction of predators;  
knowledge of parasite's life cycle allows proper application of drug treatments; (2)

**Total 11**

## Question 7

The diagram below shows the levels of antibodies in the development of active acquired immunity after exposure to an infectious agent.

- a) Match one of the points X, Y, or Z on the diagram with each of the following:
- i) the start of the primary response = X (1)
  - ii) the point of second exposure to the infectious agent = Y (1)
- b) With reference to the curve of secondary response in the diagram:
- i) explain how subsequent exposures to the disease further boost immunity.  
subsequent exposures to the disease stimulate memory cells of the immune system;  
which divide rapidly;  
to rapidly produce high levels of antibody; (3)
  - ii) Describe the relationship between the above curve of secondary response in the diagram and that for the active acquired immunity by vaccination with a booster.  
the two are virtually identical;  
the two exposures to the infectious agent are via vaccines;  
resulting in same response of immune system;  
stimulating rapid multiplication of memory cells and antibodies; (3)
- c) Describe three types of vaccine
- i) one made with heat killed pathogens; (1)
  - ii) one made with attenuated / diluted live pathogens; (1)
  - iii) one made with toxins (1)
- d) Describe two ways in which natural passive immunity may be acquired
- fetus receives maternal antibodies;  
across the placenta;  
directly into blood stream;  
in colostrum of 'first' milk; (4)

**Total 15**

# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### 3 - Transport

#### Year Set I

*Time allowed 60 minutes*

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#### Instructions:

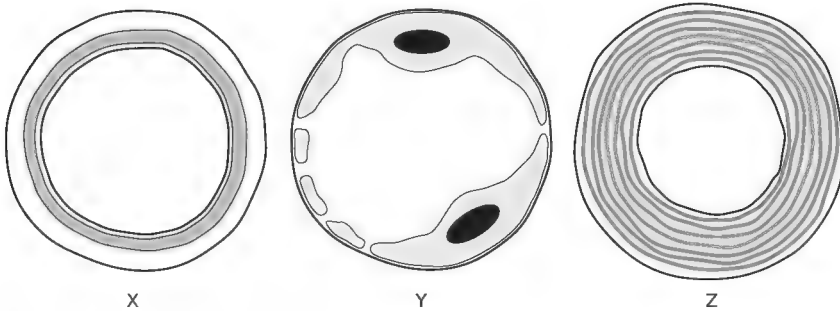
- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 60.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 50 of the marks, and 10 marks for the extended answer.
- about 36 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

## Question 1

The three diagrams below are of cross (transverse) sections of an artery, vein and capillary, not drawn to scale.



- a) i) Identify the artery, vein and the capillary.

\_\_\_\_\_ (1)

- ii) What is the diameter of an average capillary?

\_\_\_\_\_ (1)

- b) Describe how the structure of the capillary shown above is adapted to its function.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

- c) Explain in terms of lung function, why it is necessary for the blood in the lung capillaries to be under a much lower pressure than the blood in the muscle capillaries.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

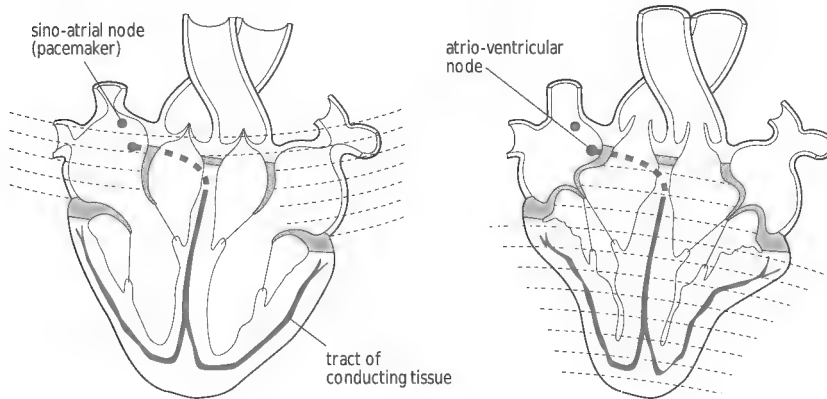
- d) Describe a difference in the structure of arteries and veins which is usually only seen in sections along the length of the vessel (longitudinal sections), and explain why this difference is rarely seen in cross sections.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**Total 13**

## Question 2

The diagrams below show vertical sections of the heart at different stages of the cardiac cycle. The spread of electrical activity through the walls is indicated by the radiating curved lines.



- a) Draw arrows on the diagrams above to show the directions in which electrical activity spreads through the walls of the heart. (2)

- b) Relate this pattern of spread of electrical activity, and the resultant contractions of the atria and ventricles in the cardiac cycle, to the direction of blood flow through the heart. (3)

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- c) Describe what causes the heart valves to open and close during the cardiac cycle. (2)

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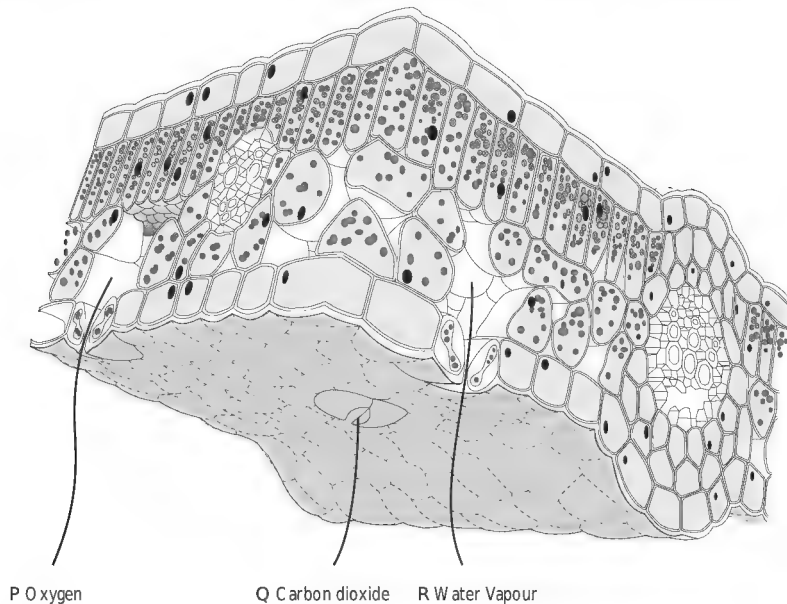
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**Total 7**

### Question 3

The diagram below is of a section through a typical leaf of a flowering plant (a mesophyte).



- a) i)** Place arrow heads on the lines P, Q, and R on the diagram passing through the stomata to show the overall direction of the diffusion of oxygen, carbon dioxide, and water respectively, at noon in conditions of average humidity. (3)
- ii)** Indicate and name on the diagram a cell from which water is evaporating before diffusing out of the leaf. (1)
- b)** With decreasing diameter of the stomata the passage of water vapour is restricted more than that of carbon dioxide. Explain the advantage of this to the plant in terms of gaseous exchanges with the environment.

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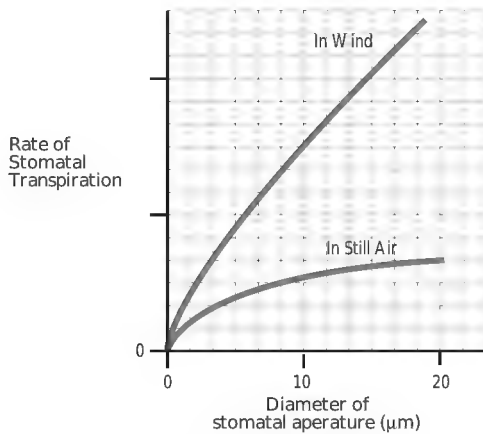


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(3)

*Question continued...*

- c) The graph below shows the relationship between the size of the stomatal aperture (hole) and the rate of loss of water vapour through the stomata under different conditions of external air movement.



Under which conditions do the stomata exert most control over the rate of loss of water vapour? Explain your answer.

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(3)

- d) Describe the features of the leaf, drawn on the previous page, which provide a large surface area to volume ratio for gaseous exchange, and the transport of substances into and out of the leaf.

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(8)

**Total 18**

#### Question 4

a) Describe the role of haemoglobin in carrying and releasing:

i) oxygen

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(3)

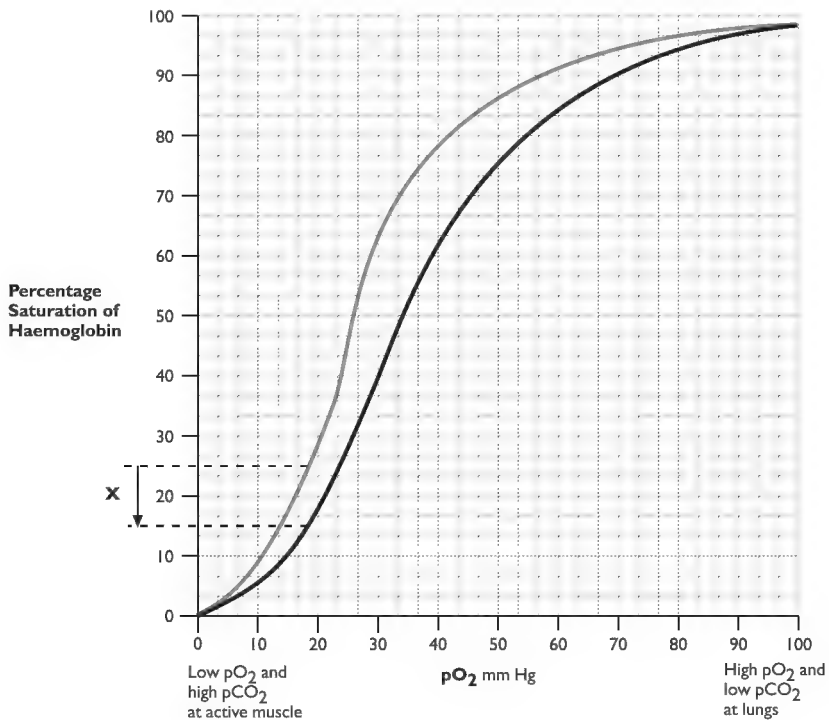
ii) carbon dioxide

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(1)



b) Study the graph below showing the association of haemoglobin with oxygen at different partial pressures of oxygen, and answer the following questions.

i) The two curves represent the percentage saturation of haemoglobin with oxygen at two different carbon dioxide concentrations. On the diagram label the curve which is at the higher carbon dioxide concentration with the letter A.

(1)

Question continues...



- 
- ii) With reference to the vertical arrow labelled X explain the significance of the difference between the two curves with respect to the delivery of oxygen to the tissues.

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(4)

- c) Explain how the difference between the the two curves could be increased by the activity of the body.

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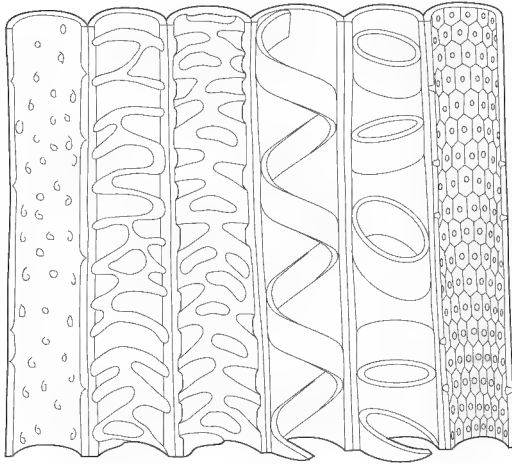
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(4)

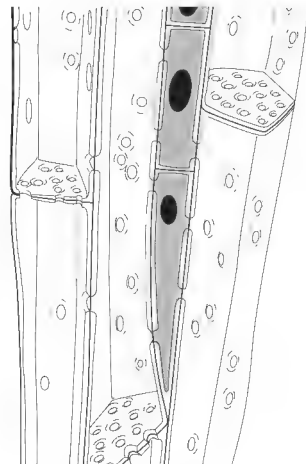
**Total 13**

## Question 5

With the aid of the diagrams below and your own knowledge answer the questions that follow.



**X**



**Y**

- a) i)** Identify tissue X, and state whether its contents in the living plant are under positive or negative pressure.

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(2)

- ii)** State the two main functions of tissue X.

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(2)

- iii)** Describe the functions of the pits in the walls of tissue X.

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(2)

Question continues....

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**b) i)** Identify tissue Y, state whether its contents in the living plant are under positive or negative pressure.

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(2)

**ii)** State the main function of tissue Y.

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(1)

**Total 9**

## Assessment Grid Biology

### 3: Transport

#### Year Set I

| Specification Section   | Question Number |   |    |    |   |   |   |   |   | Total |
|-------------------------|-----------------|---|----|----|---|---|---|---|---|-------|
|                         | 1               | 2 | 3  | 4  | 5 | 6 | 7 | 8 | 9 |       |
| 3.1 Mammalian Transport | 13              |   |    | 13 |   |   |   |   |   | 26    |
| 3.2 Mammalian Heart     |                 | 7 |    |    |   |   |   |   |   | 7     |
| 3.3 Transport in Plants |                 |   | 18 |    | 9 |   |   |   |   | 27    |

Total 60

| Assessment Objective            | Question Number |   |    |   |   | Total |
|---------------------------------|-----------------|---|----|---|---|-------|
|                                 | 1               | 2 | 3  | 4 | 5 |       |
| AO1                             |                 |   |    |   |   |       |
| Knowledge with Understanding    | 8               | 2 | 11 | 8 | 5 | 34    |
| AO2                             |                 |   |    |   |   |       |
| Application/Analysis/Evaluation | 5               | 5 | 7  | 5 | 4 | 26    |

Total 60

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# Mark Schemes for Question Paper

## Biology

### 3 - Transport

#### Year Set I

#### Instructions

; 1 mark / = alternative response

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#### Question I

The three diagrams below are of cross (transverse) sections of an artery, vein and capillary, not drawn to scale.

- a) i) Identify the artery, vein and the capillary.

X = vein; Y = capillary; Z = artery; (2)

- ii) What is the diameter of an average capillary?

6 - 8  $\mu\text{m}$  (1)

- b) Describe how the structure of the capillary is adapted to its function.

thin walled / wall one cell thick;

some also have pores in the wall / fenestrated;

diameter same as that of the red blood cells; (3)

- c) Explain in terms of lung function, why it is necessary for the blood in the capillaries of the lungs to be under a much lower pressure than that in the capillaries of the muscles.

capillaries of lungs close to / next to air in air sacs (alveoli);

if blood pressure same as that in muscle capillaries much tissue fluid exuded;

alveoli would fill with tissue fluid;

reducing surface area for gas exchange by diffusion;

increasing diffusion distance for gas exchange by diffusion; (4)

- d) Describe a difference between arteries and veins which can only be seen in sections along the length of the vessel (longitudinal sections), and explain why this difference is rarely seen in cross sections.

veins have pocket valves / arteries do not;

at intervals along their length;

therefore cross sections will tend to 'miss' them; (3)

**Total 13**

---

## Question 2

The diagrams below show vertical sections of the heart at different stages of the cardiac cycle where the spread of electrical activity through the walls is indicated by the radiating curved lines.

- a) By means of arrows on the diagram above show the directions in which electrical activity spreads through the walls of the heart  
arrows radiating downwards and across in atria and upwards in ventricles (possibly down in septum and up walls) (2)
- b) Relate this pattern of spread of electrical activity and the resultant contractions of the atria and ventricles in the cardiac cycle to the direction of blood flow through the heart.  
arrow radiating downwards in atria results in downward contraction of atria;  
forcing blood downwards into the ventricles;  
arrow radiating upwards in ventricles results in upward contraction of ventricles;  
forcing blood upwards into pulmonary arteries and main aorta; (3)
- c) Describe what causes the heart valves to open and close during the cardiac cycle.  
heart valves are passive structures incapable of initiating movement;  
pressure of blood forces valves open or shut;  
dependent upon their one-way arrangement; (2)

**Total 7**

### Question 3

The diagram is of a section through a typical leaf of a flowering plant (a mesophyte).

- a) i) Place arrow heads on the lines P, Q, and R on the diagram passing through the stomata to show the overall direction of the diffusion of oxygen, carbon dioxide, and water respectively, at noon in conditions of average humidity. (3)
- ii) **Indicate** and name on the diagram a cell from which water is evaporating before diffusing from the leaf.  
spongy mesophyll cell (1)
- b) With decreasing diameter of the stomata the passage of water vapour is restricted more than that of carbon dioxide. Explain the advantage of this to the plant in terms of gaseous exchanges with the environment.  
the main role of the stomata is for the uptake of carbon dioxide in the light;  
but must also minimise loss of water vapour;  
by decreasing size of stomata these aims are met; (3)
- c) The graph below shows the relationship between the size of the stomatal aperture (hole) and the rate of loss of water vapour through the stomata at different external air movement. Under what conditions do the stomata exert most control over the rate of loss of water vapour? Explain your answer.  
in moving air;  
as stomatal aperture increases so does rate of loss of water vapour;  
in still air little increase in rate of loss of water vapour above 5 mm (3)
- d) Describe the features of the leaf drawn above which provide a large surface area to volume ratio for gaseous exchange, and the transport of substances into and out of the leaf.  
thin flat lamina (blade);  
with large surface area of leaf;  
large intercellular air spaces between spongy mesophyll cells;  
irregular shape of spongy mesophyll cells;  
large intercellular air spaces between palisade mesophyll cells;  
sub-stomatal cavities;  
xylem tissue transporting water and inorganic ions in;  
phloem transporting mainly sucrose out; (8)

**Total 18**

---

## Question 4

- a) Describe the role of haemoglobin in carrying and releasing:
- i) oxygen  
combines to form oxyhaemoglobin at the lungs;  
reversibly;  
rapidly at first and more slowly as it nears saturation;  
unloads at the tissues due to low  $pO_2$  and acidity;  
(3)
  - ii) carbon dioxide  
small amount combines to form carbamino haemoglobin;  
(1)
- a) Study the graph below showing the association of haemoglobin with oxygen at different partial pressures and answer the following questions.
- i) The two curves represent the percentage saturation of haemoglobin with oxygen at two different carbon dioxide concentrations. On the diagram label the curve which is at the higher carbon dioxide concentration.  
right hand curve;  
(1)
  - ii) With reference to the vertical arrow labelled X explain the significance of the difference between the two curves with respect the delivery of oxygen to the tissues.  
  
arrow X indicates difference in saturation;  
at one particular oxygen level;  
more oxygen released to tissues;  
when right hand curve operating (high carbon dioxide);  
(4)
- c) Explain how the difference between the two curves could be increased by the activity of the body.  
difference depends on different levels of carbon dioxide and lactic acid;  
lowering of pH / increase in acidity;  
levels of both increased by increased respiration;  
eg as a result of increased exercise;  
(4)

**Total 13**



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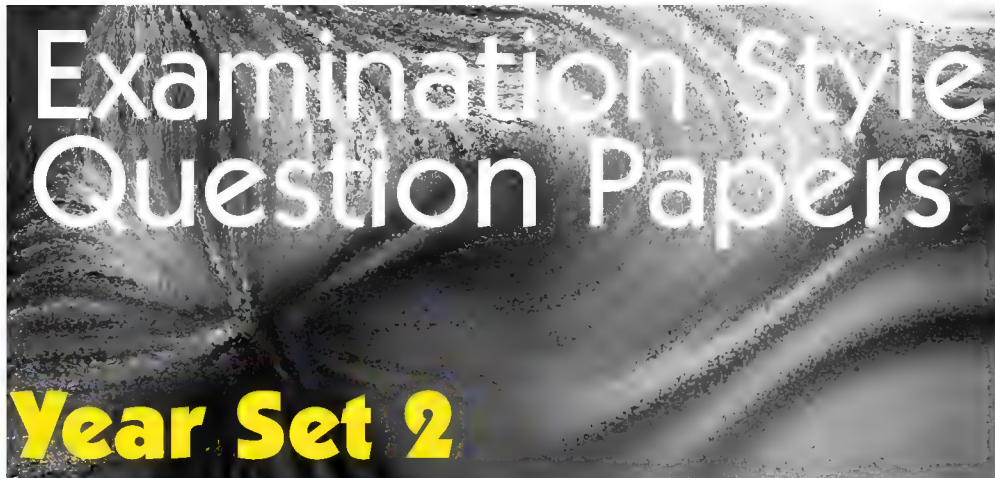
## Question 5

With the aid of the diagrams below and your own knowledge answer the questions below.

- a) i) Identify X, state whether its contents in the living plant are under positive or negative pressure.  
X = xylem vessels;  
contents under negative pressure; (2)
- ii) State the two main functions of X  
water transport;  
support; (2)
- iii) Describe the function of the pits in the walls of tissue X.  
allows continuity of water 'column' between adjacent vessels;  
allows blockages eg air bubbles to be by-passed; (2)
- b) i) Identify Y, state whether its contents in the living plant are under positive or negative pressure.  
Y = phloem sieve tube elements;  
contents under positive pressure; (2)
- ii) State the main function of Y.  
transport of organic compounds mainly sucrose; (1)

**Total 9**

# Biology



- 1 - Biology Foundation
- 2 - Human Health & Disease
- 3 - Transport

Complete with Assessment Grids & Mark Schemes

**FELTHAM PRESS**

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# Examination Style Question Papers

## Biology

### I - Biology Foundation Year Set 2

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

*Time allowed 1 hour 30 minutes*

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#### Instructions:

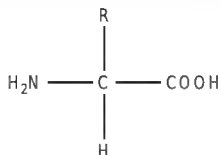
- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- about 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- This type of paper would carry 30 per cent of the total marks for AS level, and 15 per cent of the total marks for A level.
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

## Question 1

The structural formula of an amino acid is shown below.



- a) i There are about 20 different types of amino acid to be found in proteins from living organisms, explain how the structural formula shown above applies to them all even though they are different.

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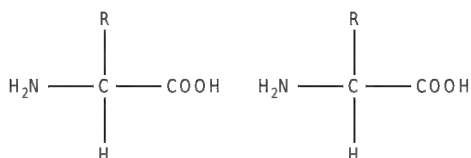
(3)

- ii) On the diagram below show how two amino acids combine.

(2)

- iii) Name the type of reaction of which this combination is an example.

(1)



- iv) Name the type of bond formed by the combination of two amino acids.

(1)

- b) Explain how only about 20 different types of amino acids can form the huge variety of proteins found in living organisms.

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(2)

- c) Explain the meaning of the following terms with regard to protein structure, give an example of each:

- i) secondary structure;

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(2)

- ii) tertiary structure;

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(2)

- iii) quaternary structure;

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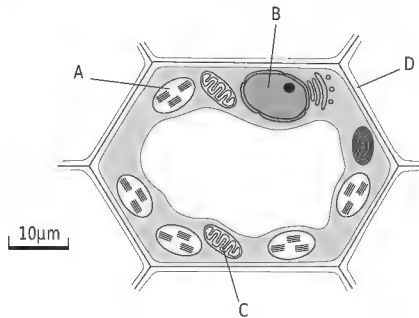
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(2)

**Total 15**

**Question 2**

Study the diagram below of a generalised plant cell as seen under the electron microscope and answer the questions that follow.



- a)** Identify and give a function for each of the structures labelled A to D on the diagram.

**A**

---

(2)

**B**

---

(2)

**C**

---

(2)

D

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(2)

- b)** Describe how a cell, like the one in the diagram above, differs from a typical bacterial cell. (In this question one mark is available for the quality of written communication.)

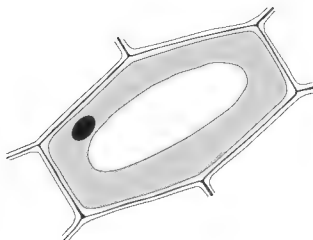
[illegible]

(7)

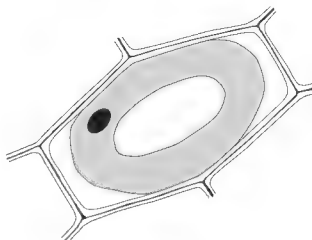
**Total 15**

### Question 3

The diagrams below show two plant cells, each bathed in a different external solution.



Cell A



Cell B

- a) i) Identify the cell which is in a solution more dilute than the cell contents.

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(1)

- ii) Describe the appearance of the cell which is in a solution more concentrated than the cell contents.

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(2)

- b) Describe and explain what would happen to animal cells e.g. human red blood cells if they are placed in a solution with a water potential greater than their contents.

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(3)

- c) Explain why, when respiration is inhibited in cells bathed in pure water, substances, especially ions, are released from the cells.

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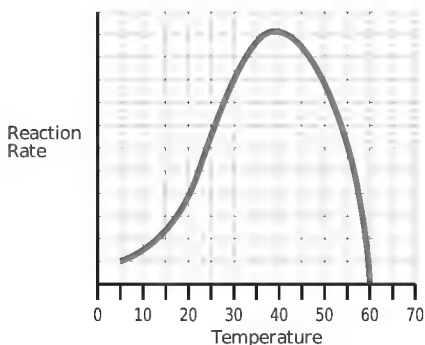
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(4)

**Total 10**

#### Question 4

The graph shows the effect of changing temperature on the rate of an enzyme controlled reaction.



- a) i) Identify the optimum temperature for this enzyme.

\_\_\_\_\_

(1)

- ii) Identify the temperature at which the enzyme is completely denatured.

\_\_\_\_\_

(1)

- b) i) Explain why the rate of reaction slows at temperatures below the optimum.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(2)

- ii) Explain why the rate of reaction slows at temperatures above the optimum.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(3)

- c) A graph of rate of enzyme reaction against pH would have a similar shape to the one above, but there is an important difference between the state of the enzyme at the lowest temperature and the state of the enzyme at the lowest pH. Explain what this difference is.

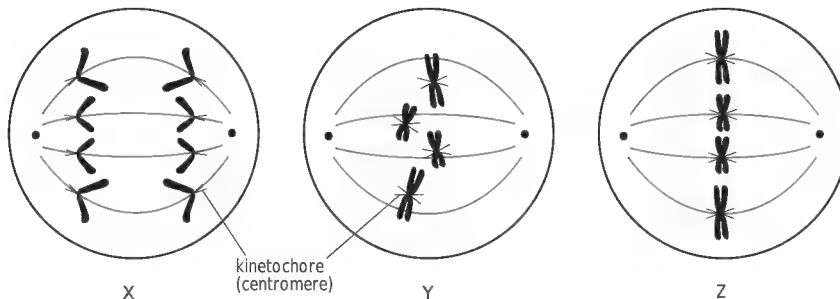
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(3)

**Total 10**

## Question 5

Study the diagrams below of different stages in mitosis and answer the following questions.



- a) i) Write the letters in the correct order to match the sequence in which these stages occur in mitosis.

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---

(1)

- ii) Describe what is occurring with respect to the chromosomes / chromatids in each of the stages shown above in diagrams Y and Z.

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(4)

- iii) Explain the shape of the chromosomes in diagram X.

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(3)

- b) Distinguish between the terms chromosome and chromatid.

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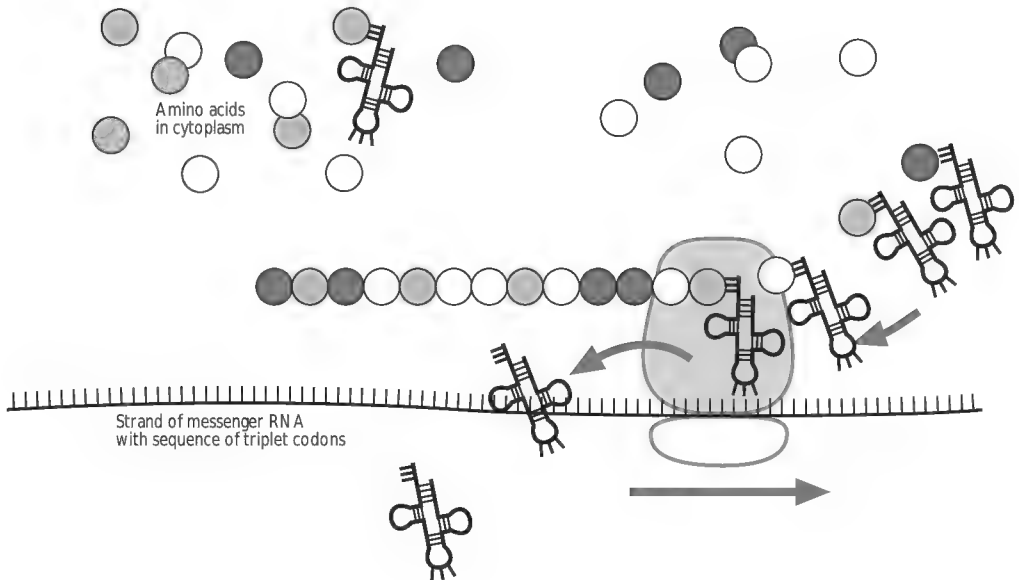
(4)

**Total 12**



## Question 6

Study the diagram of protein synthesis below and answer the following questions.



a) On the diagram label the following:

- |                                    |     |
|------------------------------------|-----|
| i) a transfer RNA (tRNA) molecule; | 1)  |
| ii) an anti-codon;                 | (1) |
| iii) the ribosome;                 | (1) |
| iv) the polypeptide;               | (1) |

Question continued...

---

**b)** With regard to the formation of a polypeptide chain:

**i)** define the term 'translation';

\_\_\_\_\_  
\_\_\_\_\_ (1)

**ii)** what is the function of the ribosome;

\_\_\_\_\_  
\_\_\_\_\_ (1)

**iii)** which nucleotide base is present in mRNA but not in DNA?

\_\_\_\_\_  
\_\_\_\_\_ (1)

**iv)** describe how a polypeptide chain gives rise to an active protein enzyme molecule.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**c)** Explain the significance in protein synthesis of the fact that the genetic code is 'non-overlapping'.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

**Total 14**

## Question 7

- a) Give definitions of the following terms with reference to a named ecosystem and a named example of each.

i) Niche

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(1)

ii) Population

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(1)

iii) Community

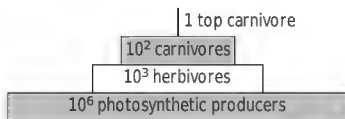
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(1)

- b) The diagram below shows a simplified representation of a pyramid of numbers.



- i) Give a named example of a type of organism which occurs at each trophic level in the pyramid of numbers based on a food chain in a named ecosystem.

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(4)

- ii) By reference to named examples of different types of organism, describe how a series of trophic levels in a food chain may not form a pyramid of numbers. (In this question one mark is available for quality of written communication.)

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(7)

**Total 14**

# Assessment Grid

## Biology

### I - Biology Foundation

#### Year Set 2

| Specification Section          | Question Number |    |    |    |    |    |    | Total |
|--------------------------------|-----------------|----|----|----|----|----|----|-------|
|                                | 1               | 2  | 3  | 4  | 5  | 6  | 7  |       |
| I.1 Cell Structure             | 15              |    |    |    |    |    |    | 15    |
| I.2 Biological Molecules       |                 | 15 |    |    |    |    |    | 15    |
| I.3 Enzymes                    |                 |    | 10 |    |    |    |    | 10    |
| I.4 Cell Membranes/Transport   |                 |    |    | 10 |    |    |    | 10    |
| I.5 Genetic Control of Protein |                 |    |    |    | 12 |    |    | 12    |
| I.6 Nuclear Division           |                 |    |    |    |    | 14 |    | 14    |
| I.7 Energy and Ecosystems      |                 |    |    |    |    |    | 14 | 14    |

Total 90

| Assessment Objective            | Question Number |    |   |   |   |    |   | Total |
|---------------------------------|-----------------|----|---|---|---|----|---|-------|
|                                 | 1               | 2  | 3 | 4 | 5 | 6  | 7 |       |
| AO1                             |                 |    |   |   |   |    |   |       |
| Knowledge with Understanding    | 10              | 11 | 3 | 7 | 5 | 10 | 7 | 53    |
| AO2                             |                 |    |   |   |   |    |   |       |
| Application/Analysis/Evaluation | 5               | 4  | 7 | 3 | 7 | 4  | 7 | 37    |

Total 90

# Mark Schemes for Question Paper

## Biology

### I - Biology Foundation Year Set 2

#### Instructions

; = 1 mark    / = alternative response

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#### Question I

The structural formula of an amino acid is shown below.

- a) i) There are about 20 different types of amino acid to be found in proteins from living organisms, explain how the structural formula shown above applies to them all even though they are different.  
the R group varies in structure;  
providing the variation between them;  
but the rest of the molecule is always the same; (3)
- ii) On the diagram below show how two amino acids combine.  
elimination of the elements of water;  
correctly indicated; (2)
- iii) Name the type of reaction of which this combination is an example.  
condensation reaction; (1)
- iv) Name the type of bond formed by the combination of two amino acids.  
peptide bond; (1)
- b) Explain how only about 20 different types of amino acids can form the huge variety of proteins found in living organisms.  
each type used any number of times;  
in any number of sequences; (2)
- c) Explain the meaning of the following terms with regard to protein structure, giving an example of each:
- i) secondary structure;  
first 'shaping' of the polypeptide chain typically as a result of hydrogen bonding;  
e.g. alpha helix / beta sheets; (2)
- ii) tertiary structure;  
further foldings of the secondary structure as a result of further / and different bonding;  
giving a 'globular' shape;  
e.g. biologically active molecules ie enzymes; (2)
- iii) quaternary structure;  
aggregation of polypeptide chains;  
e.g. haemoglobin consists of four polypeptide chains; (2)

**Total 15**

---

## Question 2

Study the diagram below of a generalised plant cell as seen under the electron microscope, and answer the questions that follow.

- a) Identify and give a function for each of the structures labelled A to D on the diagram.

A = Chloroplast;

photosynthesis;

B = Nucleus;

controls cell via DNA/RNA

C = Mitochondrion;

aerobic respiration;

D = Cellulose cell wall;

support / protection;

(8)

- b) Describe how a cell like the one in the diagram above differs from a typical bacterial cell.

(Quality of written communication assessed in this answer.)

bacterial cell:

has no nucleus;

no chloroplasts;

no mitochondria;

no large central vacuole;

no endoplasmic reticulum;

in fact no membrane bound organelles;

has rings of DNA / plasmids;

has mesosomes;

(6)

Q - legible text with accurate spelling, punctuation and grammar;

(1)

**Total 15**

---

### Question 3

The diagrams below show two plant cells, each bathed in a different external solution.

- a) i) Identify the cell which is in a solution more dilute than the cell contents.  
cell A; (1)
- ii) Describe the appearance of the cell which is in a solution more concentrated than the cell contents.  
the cell membrane is withdrawn from the cell wall;  
the central vacuole is smaller than in cell A; (2)
- b) Describe and explain what would happen to animal cells e.g. human red blood cells if they are placed in a solution with a water potential greater than their contents.  
water would enter by osmosis (endosmosis);  
cells would increase in volume (swell);  
cell membrane would be stretched;  
and burst if water potential gradient high enough; (3)
- c) Explain why, when respiration is inhibited in cells bathed in pure water, substances, especially ions, are released from the cells.  
in pure water the diffusion gradient is from the more concentrated cell contents to the pure water;  
this gradient is maintained by active ion uptake;  
using energy from respiration / ATP;  
if respiration is inhibited active uptake is reduced and substances diffuse out of the cell into the surrounding water until equilibrium is reached;  
if respiration inhibited completely, membrane breaks down and all cell contents are released into the surrounding water; (4)

**Total 10**

#### Question 4

The graph shows the effect of changing temperature on the rate of an enzyme controlled reaction.

- a) i) Identify the optimum temperature for this enzyme.  
37°C; (1)
- ii) Identify the temperature at which the enzyme is completely denatured.  
60°C (1)
- b) i) Explain why the rate of reaction slows at temperatures below the optimum.  
rate of collisions of reacting molecules temperature dependent;  
the lower the temperature the lower the rate of collisions / kinetic energy;  
lowers the rate of all chemical reactions including enzyme catalysed; (3)
- ii) Explain why the rate of reaction slows at temperatures above the optimum.  
enzyme molecules progressively denatured / disrupted;  
cannot form enzyme substrate complexes;  
rate of reaction slows despite increased rate of collision; (2)
- c) A graph of rate of enzyme reaction against pH would have a similar shape as the one above, but there is an important difference between the state of the enzyme at the lowest temperature and the state of the enzyme at the lowest pH. Explain what this difference is.  
at lowest temperature enzyme not denatured;  
reversible;  
at lowest pH enzyme denatured;  
irreversible; (3)

**Total 10**



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## Question 5

Study the diagram below of different stages in mitosis and answer the following questions.

- a) i) Write the letters in the sequence that these stages occur in mitosis.

Y, Z, X

(1)

- ii) Describe what is occurring with respect to the chromosomes / chromatids in each of the stages shown in diagrams Y and Z.

Y - the chromosomes (each of two chromatids) are just formed;

and moving towards the equator of the nuclear spindle apparatus;

Z - the chromosomes (each of two chromatids) are arranged on the equator;

by means of the kinetochore (centromere) attached to fibres of the spindle apparatus;

(4)

- iii) Explain the shape of the chromosomes in diagram X.

the kinetochores (centromeres) are the centres of movement of the chromosomes;

they lead the way along the spindle fibres towards the centrioles at the poles of the spindle;

the 'arms' of the chromosomes trail behind;

(3)

- b) Distinguish between the terms chromosome and chromatid.

chromosomes appear (condense) containing a diploid (double 'dose') of DNA;

organised into two duplicate parts - chromatids;

sharing a common kinetochore;

chromatids become new 'daughter' chromosomes when the kinetochore divides;

(4)

**Total 12**

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## Question 6

Study the diagram of protein synthesis and answer the following questions.

- a) On the diagram label the following:
- i) a transfer RNA (tRNA) molecule; (1)
  - ii) an anti-codon; (1)
  - iii) the ribosome; (1)
  - iv) the polypeptide; (1)
- b) With regard to the formation of a polypeptide chain:
- i) define the term 'translation';  
the conversion of the genetic code on the mRNA into the reality of a polypeptide chain; (1)
  - ii) what is the function of the ribosome;  
to organise the synthesis of the polypeptide chain; (1)
  - iii) which nucleotide is present in RNA but not DNA;  
uracil; (1)
  - iv) describe how a polypeptide chain gives rise to an active protein enzyme molecule.  
as it gets longer, attractions between parts of the chain;  
e.g. forming hydrogen bonds;  
result in folding of chain;  
complex three dimensional shape formed with an active site; (3)
- c) Explain the significance in protein synthesis of the fact that the genetic code is 'non-overlapping'.
- the genetic code can only be read from a specific starting point;
  - which fixes the base sequences within each triplet codon which is 'read' by mRNA;
  - therefore each strand of mRNA produces one specific polypeptide strand;
  - if there was no fixed 'start' codon, subsequent codons would be 'read' differently;
  - the bases on one codon cannot 'overlap' into another; (4)

**Total 14**

---

## Question 7

- a) Give definitions of the following terms.
- i) Niche  
an organisms role / 'occupation'; (1)
  - ii) Population  
interbreeding members of the same species; (1)
  - iii) Community  
an interdependent collection of populations; (1)
- b) The diagram gives a simplified representation of a pyramid of numbers.
- i) Give a named example of a type of organism which occurs at each trophic level in the pyramid of numbers based on a food chain in a named community.  
appropriate examples of:  
producers e.g. heathers in a heathland community;  
primary consumers e.g. caterpillars;  
secondary consumers e.g. insectivorous birds;  
tertiary consumers e.g. birds of prey; (4)
  - ii) By reference to named examples of different types of organism describe how a series of trophic levels in a food chain may not form a pyramid of numbers. (In this question one mark is available for the quality of written communication).  
any acceptable account e.g.:  
single producer e.g. Beech tree;  
supporting huge numbers of primary consumers;  
e.g. insects and their larvae;  
and detritivores on the leaf litter;  
supporting a much smaller number of insectivorous birds;  
which support larger numbers of parasites (6)  
Q - clear, well organised using specialist terms; (1)

**Total 14**

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# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### 2 - Human Health and Disease

#### Year Set 2

*Time allowed 1 hour 30 minutes*

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#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- about 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

### Question 1

- a) Explain, with one example of each, what is meant by the following categories of disease or illness:

**i) degenerative,**

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(2)

**ii) inherited,**

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(2)

- iii) self-inflicted,

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(2)

**iv) deficiency,**

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(2)

- b)** Explain the significance of, and the problems associated with the Human Genome Project for the screening and treatment of inherited diseases. (In this question one mark is available for the quality of written communication.)

[illegible]

(7)

**Total 15**

## Question 2

- a) Distinguish between essential and non essential amino acids.

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(4)

- b) i) Give a definition of the term 'vitamin'.

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(2)

- ii) In the light of your definition assess the status of vitamin D as a vitamin.

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(4)

- iii) List two major sources of vitamin D in the diet.

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(2)

- c) i) Explain why at the height of the industrial revolution Rickets was known as 'a British Disease'.

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(4)

- ii) What are the symptoms of a lack of Vitamin A in the diet

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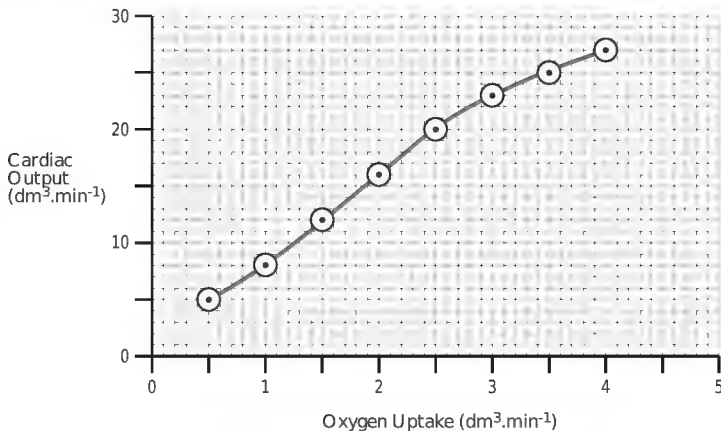
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(2)

**Total 18**

### Question 3

Study the graph below of cardiac output plotted against oxygen uptake at increasing sub-maximal work rates on a cycle ergometer and then answer the following questions.



- a) i) Briefly describe the relationship between oxygen uptake and cardiac output shown in the graph.

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(3)

- ii) Explain in terms of heart and lung function why they are related in this way.

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(4)

- b) Why does an aerobically fit individual generally have a lower resting heart rate than an aerobically unfit individual of the same size and sex? (In this question one mark is available for the quality of written communication.)

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(7)

**Total 14**

## Question 4

Study the chart below setting out various heart disease risk factors and answer the following questions.

| Age               | Sex                     | Weight                                  | % Animal Fat in Diet  |              |
|-------------------|-------------------------|-----------------------------------------|-----------------------|--------------|
| 10–20<br>= 1      | Female under 40<br>= 1  | More than 2kg below<br>ideal weight = 0 | No animal fat<br>= 1  |              |
| 21–30<br>= 2      | Female 40–50<br>= 2     | Within 2kg of<br>ideal weight = 1       | 10% animal fat<br>= 2 |              |
| 31–40<br>= 3      | Female over 50<br>= 3   | 15kg overweight<br>= 2                  | 20% animal fat<br>= 3 |              |
| 41–50<br>= 4      | Male<br>= 5             | 20kg overweight<br>= 3                  | 30% animal fat<br>= 4 |              |
| 51–60<br>= 5      | Stocky male<br>= 6      | 25kg overweight<br>= 5                  | 40% animal fat<br>= 5 |              |
| 61 & over<br>= 8  | Bald stocky male<br>= 7 | 30kg overweight<br>= 7                  | 50% animal fat<br>= 7 | <b>Total</b> |
| <b>Sub-totals</b> |                         |                                         |                       |              |

| Exercise                              | Tobacco Smoking                    | History of Heart Disease    | Blood Pressure                   |                    |
|---------------------------------------|------------------------------------|-----------------------------|----------------------------------|--------------------|
| Hard manual job<br>& exercise = 2     | Non smoker<br>= 0                  | None<br>= 1                 | Upper reading 100<br>= 1         |                    |
| Manual job &<br>moderate exercise = 2 | Cigar or pipe smoker<br>= 1        | 1 Relative over 60<br>= 2   | Upper reading 120<br>= 2         |                    |
| Office job &<br>hard exercise = 3     | 10 cigarettes a day or less<br>= 3 | 2 Relatives over 60<br>= 3  | Upper reading 140<br>= 3         |                    |
| Office job &<br>moderate exercise = 5 | 20 cigarettes a day<br>= 5         | 1 Relative under 60<br>= 4  | Upper reading 160<br>= 4         |                    |
| Office job &<br>light exercise = 6    | 30 cigarettes a day<br>= 7         | 2 Relatives under 60<br>= 6 | Upper reading 180<br>= 6         |                    |
| No exercise<br>at all = 8             | 40 cigarettes a day<br>= 11        | 3 Relatives under 60<br>= 7 | Upper reading 200<br>or more = 8 | <b>Total</b>       |
| <b>Sub-totals</b>                     |                                    |                             |                                  |                    |
|                                       |                                    |                             |                                  | <b>Grand Total</b> |

- a) i) Explain why the lowest total score for all the columns on the chart is not zero.

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(2)

Question continued....



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ii) Calculate the percentage by which the maximum risk score can be reduced by exercise.

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(2)

iii) In the light of your answer to ii) above, explain whether you would advise an exercise regime for sedentary people who have been cleared by a physician to take part.

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(1)

b) i) Describe the types of people who would have the highest and lowest risk factor totals

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(2)

ii) Briefly explain the advice that you would give to the individual with the highest risk.

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(3)

**Total 10**

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### Question 5

- a) i) In terms of the effects of tobacco smoke on the gaseous exchange system, explain the observation that when smokers first stop smoking they often cough more.

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(3)

- ii) Describe three other effects of tar and other carcinogens in tobacco smoke on the gaseous exchange system.

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(3)

- b) Describe the symptoms of:

- i) chronic bronchitis,

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(3)

- ii) emphysema (chronic obstructive pulmonary disease),

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(3)

- c) i) It is not unusual for smokers who survive apparently unharmed to dismiss the risks associated with smoking. Explain why this demonstrates a misunderstanding of the interpretation of statistics, and why, if anybody has concern for others, such an attitude is misplaced.

---

---

(2)

- ii) If the chances of landing a 'head' on each toss of a coin is 50:50, and after tossing a coin 4 times four 'tails' have been scored, explain what the chances are that on the next toss the result will be a head.

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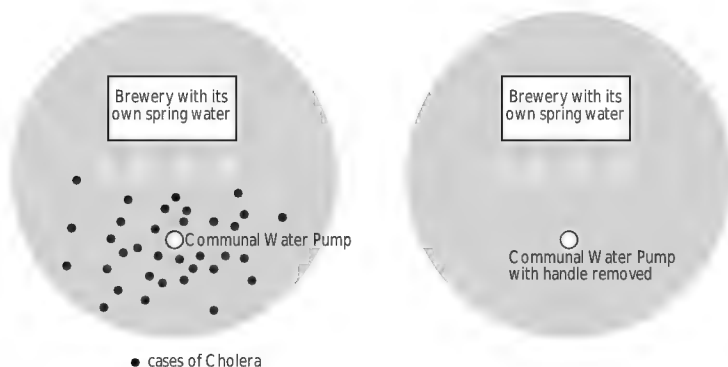
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(2)

**Total 16**

## Question 6

In a famous study from Soho in London in 1854 a Dr Snow recorded the number of cases of cholera in a localised outbreak. He then had the handle of the communal water pump removed and the outbreak came under control. A simplification of two of his main findings is shown in the diagrams below.



- a) Describe and explain the patterns of the occurrence of the disease shown in the maps with regard to:

i) the brewery.

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(2)

ii) the pump

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(3)

- b) Describe the main means of transmission of cholera.

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(2)

- c) Describe the meaning and importance of 'symptomless carriers'

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(2)

- d) Explain how attempts at the severe restriction of travel and trade with cholera epidemic areas are often counterproductive.

---



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(2)

**Total 11**

---

### Question 7

- a) B-lymphocytes form memory cells after meeting an antigen, e.g. a pathogen, in the body. These memory cells allow the body to 'remember' antigens it has met before and produce a much faster immune response to them the second time around.

Describe what is meant by the terms:

- i) antigen

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---

(1)

- ii) antibody

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(1)

- iii) pathogen

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(1)

- b) When they do meet a familiar antigen, B-lymphocyte memory cells divide and form new antibody producing plasma cells. Some memory cells remain so that the body can respond in this way to any number of future infections with the same antigen.

- i) Describe the relationship between pathogens and antigens.

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(1)

- ii) Explain how the immunity to some diseases lasts a life time, but some illnesses can be suffered more than once.

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(2)

**Total 6**

## Assessment Grid Biology

### 2: Human Health and Disease Year Set 2

| Specification Section         | Question Number |    |    |    |    |    |   |   |   | Total |
|-------------------------------|-----------------|----|----|----|----|----|---|---|---|-------|
|                               | 1               | 2  | 3  | 4  | 5  | 6  | 7 | 8 | 9 |       |
| 2.1 Health and Disease        | 15              |    |    |    |    |    |   |   |   | 15    |
| 2.2 Diet                      |                 | 18 |    |    |    |    |   |   |   | 18    |
| 2.3 Gas Exchange and Exercise |                 |    | 14 |    |    |    |   |   |   | 14    |
| 2.4 Smoking and Disease       |                 |    |    | 10 | 16 |    |   |   |   | 26    |
| 2.5 Infectious Diseases       |                 |    |    |    |    | 11 |   |   |   | 11    |
| 2.6 Immunity                  |                 |    |    |    |    |    | 6 |   |   | 6     |

Total 90

| Assessment Objective            | Question Number |    |    |   |   |   |   | Total |
|---------------------------------|-----------------|----|----|---|---|---|---|-------|
|                                 | 1               | 2  | 3  | 4 | 5 | 6 | 7 |       |
| AO1                             |                 |    |    |   |   |   |   |       |
| Knowledge with Understanding    | 11              | 8  | 11 | 5 | 9 | 6 | 3 | 53    |
| AO2                             |                 |    |    |   |   |   |   |       |
| Application/Analysis/Evaluation | 4               | 10 | 3  | 5 | 7 | 5 | 3 | 37    |

Total 90

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# Mark Schemes for Question Paper

## Biology

### 2 - Human Health and Disease

#### Year Set 2

#### Instructions

; = 1 mark    / = alternative response

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#### Question 1

- a) Explain, with one example of each, what is meant by the following categories of disease or illness:
- i) degenerative,  
progressive associated with disuse / age;  
Alzheimer's; (2)
  - ii) inherited,  
passed from generation to generation in the genetic material / chromosomes;  
haemophilia / cystic fibrosis; (2)
  - iii) self-inflicted,  
damage caused voluntarily to self;  
cirrhosis of the liver; (2)
  - iv) deficiency,  
as a result of a missing nutrient;  
scurvy; (2)
- b) Explain the significance of, and the problems associated with the Human Genome Project for the screening and treatment of inherited diseases. (In this question one mark is available for the quality of written communication.)
- knowledge of the base sequence of the human chromosome set (genome);  
establishes reference framework;  
against which mutations may be identified;  
enabling mutated genes to be replaced by correct engineered versions;  
or depending on time of screening and moral climate termination of pregnancy;  
screening poses problems of misuse of information;  
prenatal screening of population poses problems of parental abuse;  
distortion of sex ratios;  
and selection of commercial traits;  
postnatal screening poses problems for life and health insurance;  
psychological condition of individual affected; (6)
- Q - legible text with accurate spelling, punctuation and grammar; (1)

**Total 15**

---

## Question 2

- a) Distinguish between essential and non essential amino acids.  
essential amino acids must be present in sufficient amounts in the diet;  
to prevent deficiencies;  
body unable to interconvert from other amino acids at sufficient rate;  
non essential amino acids do not have to be present in the diet;  
can be interconverted from other amino acids at sufficient rate; (4)
- b) i) Give a definition of the term 'vitamin'.  
complex organic substance essential in the diet;  
active in very small amounts; (2)
- ii) In the light of your definition assess the status of vitamin D as a vitamin.  
most requirements for vitamin D synthesised in the body;  
as a result of the action of sunlight (UV) on the skin;  
from cholesterol precursor;  
not essential in the diet;  
dietary source only needed to 'top' up skin supply; (4)
- ii) List two major sources of vitamin D in the diet.  
fish and products;  
dairy products; (2)
- c) i) Explain why at the height of the industrial revolution Rickets was known as 'a British Disease'.  
heavy air pollution;  
long working hours;  
virtually no exposure of skin to sufficient sunlight;  
poor diet: lack of Vitamin D, lack of Calcium.  
typical conditions of Britain in the industrial revolution; (4)
- ii) What the symptoms of a lack of Vitamin A in the diet?  
Nightblindness;  
Dry skin;  
Reduced resistance to infection (2)

**Total 18**

---

### Question 3

Study the graph of cardiac output plotted against oxygen uptake at increasing sub-maximal work rates on a cycle ergometer and then answer the following questions.

- a) i) Briefly describe the relationship between oxygen uptake and cardiac output shown in the graph.

as one increases so does the other;  
proportionally / linearly;  
with increasing intensity of effort;

(3)

- ii) Explain in terms of heart and lung function why they are related in this way.

oxygen uptake in the lungs is by diffusion of oxygen into blood from alveoli;  
blood supply is via the pulmonary arteries from the heart;  
blood leaving lungs in pulmonary veins is always saturated with oxygen at sea level;  
increased uptake of oxygen is achieved with increased flow in pulmonary arteries;  
supplied by increased cardiac output;

(4)

- b) Why does an aerobically fit individual generally have a lower resting heart rate than an aerobically unfit individual of the same size and sex?

heart rate related to demand by tissues for oxygen;  
cardiac output related to demand by tissues for oxygen;  
at rest the demand for oxygen of the two is the same;  
the aerobically fitter individual will have a larger stroke volume;  
as a result of increased contractility of ventricle walls;  
and possibly increased volume of ventricles (athlete's heart);  
cardiac output is a function of heart rate and stroke volume;  
therefore same cardiac output achieved with a slower resting heart rate;

(6)

Q - clear well organised using specialist terms.

(1)

**Total 14**



---

## Question 4

Study the chart setting out various heart disease risk factors and answer the following questions.

- a) i) Explain why the lowest total score for all the columns on the chart is not zero.  
there are many unknown factors involved in heart disease;  
most heart attacks not clearly correlated with risk factors;  
cannot eliminate inherited risks; (2)
- ii) Calculate the percentage by which the maximum risk score can be reduced by exercise.  
6/63;  
 $\times 100 = 9.5\%$  (2)
- iii) In the light of your answer to b) ii) above, explain whether you would advise an exercise regime for sedentary people who have been cleared by a physician to take part.  
yes, any reduction in risk is useful;  
but only of limited value; (1)
- b) i) Describe the types of people who would have the highest and lowest risk factor totals  
Score 63 - bald, stocky male over 61  
Score 7 - female age 10 - 20, (2)
- ii) Briefly explain the advice that you would give to the individual with the highest risk.  
stop smoking;  
and / or reduce progressively;  
gives the biggest reduction of risk of 11;  
reduce the percentage of animal fats in the diet reduction of risk of up to 5;  
unrealistic to hope to achieve no animal fat in diet after such a high original intake;  
start a carefully monitored progressive programme of aerobic exercise;  
the reduction of animal fats and progressive exercise should result in weight loss;  
relaxation only has marginal effects on essential hypertension (blood pressure); (3)

**Total 10**

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## Question 5

- a) i) In terms of the effects of tobacco smoke on the gaseous exchange system, explain the observation that when smokers first stop smoking they often cough more.
- tobacco smoke contains substance that paralyses cilia in respiratory tract;  
that are involved in the cough reflex in clearing the airways;  
on stopping smoking cilia become active again and coughing more frequent; (3)
- ii) Describe three other effects of tar and other carcinogens in tobacco smoke on the gaseous exchange system.
- tar accumulates and blocks bronchioles and alveoli;  
tar stimulates production of excess mucus which blocks bronchioles and alveoli;  
carcinogens trigger uncontrolled mitotic cell division in epithelia of airways; (3)
- b) Describe the symptoms of:
- i) chronic bronchitis,  
enlarged bronchial mucous glands;  
produce excess of mucus, severe cough;  
frequently complicated by acute infections; (3)
- ii) emphysema (chronic obstructive pulmonary disease),  
alveoli enlarged and damaged;  
reducing the surface area for gaseous exchange;  
causing breathlessness and secondary infection; (3)
- c) i) It is not unusual for smokers who survive apparently unharmed to dismiss the risks associated with smoking. Explain why this demonstrates a misunderstanding of the interpretation of statistics, and why, if anybody has concern for others, such an attitude is misplaced.
- risk factors based on probabilities associated with demographic studies;  
do not apply to single individuals with their individual make-up, e.g. non smokers die of lung cancer;  
surviving smokers act as a focus for others to misinterpret statistics;  
non-surviving smokers not evident to balance view of risk; (2)
- ii) If the chances of landing a 'head' on each toss of a coin is 50:50, and after tossing a coin 4 times four 'tails' have been scored, explain what the chances are that on the next toss the result will be a head.
- 50:50;  
as probabilities apply to each trial independently; (2)

**Total 16**

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## Question 6

In a famous example from Soho in London in 1854 a Dr Snow recorded the number of cases of cholera in an outbreak. He then had the handle of the communal water pump removed and the outbreak came under control. A simplification of two of his main findings is shown in the diagrams below.

- a) Describe and explain the patterns of the occurrence of the disease shown in the maps with regard to:
- i) the brewery.  
no cases;  
independent supply of uncontaminated spring water; (2)
  - ii) the pump  
cases radiate from around pump;  
removal of handle (ie stop use of pump) outbreak halted;  
therefore pump source of contaminated water supply; (3)
- b) Describe the main means of transmission of cholera.  
contaminated faeces;  
reaching water and food supplies; (2)
- c) Describe the meaning and importance of 'symptomless carriers'  
most people infected with cholera show no symptoms;  
but spread infection; (2)
- d) Explain how attempts at the severe restriction of travel and trade with cholera epidemic areas are often counterproductive.  
outbreaks concealed;  
preventing preventative measures being taken; (2)

**Total 11**

---

## Question 7

- a) B-lymphocytes form memory cells after meeting an antigen, e.g. a pathogen, in the body. These memory cells allow the body to 'remember' antigens it has met before and produce a much faster immune response to them the second time around.

Describe what is meant by the terms:

- i) antigen

compound (typically protein or glycoprotein) which is recognised and attacked by antibodies; (1)

- ii) antibody

compound (protein) which recognises and attacks antigens; (1)

- iii) pathogen

disease causing organism; (1)

- b) When they do meet a familiar antigen, B-lymphocyte memory cells divide and form new antibody producing plasma cells. Some memory cells remain so that the body can respond in this way to any number of future infections with the same antigen.

- i) Describe the relationship between pathogens and antigens.

pathogens have specific protein / glycoproteins on their cell surface membranes which act as antigens to antibodies in the host; (1)

- ii) Explain how the immunity to some diseases lasts a life time, but some illnesses can be suffered more than once.

memory cells vary in longevity;

long lasting (confer life time immunity) / short lasting allow further invasions; (2)

**Total 6**

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# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

### 3 - Transport

#### Year Set 2

*Time allowed 60 minutes*

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#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 60.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 50 of the marks, and 10 marks for the extended answer.
- about 36 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

---

## Question 1

**a)** Give brief descriptions of each of the following:

**i)** blood plasma

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(3)

**ii)** tissue fluid

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---

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(2)

**iii)** lymph

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---

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(2)

**b) i)** Describe one difference between a blood capillary and a lymphatic capillary.

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(1)

**ii)** Describe how the lymph is moved through the lymphatic system back to the circulation.

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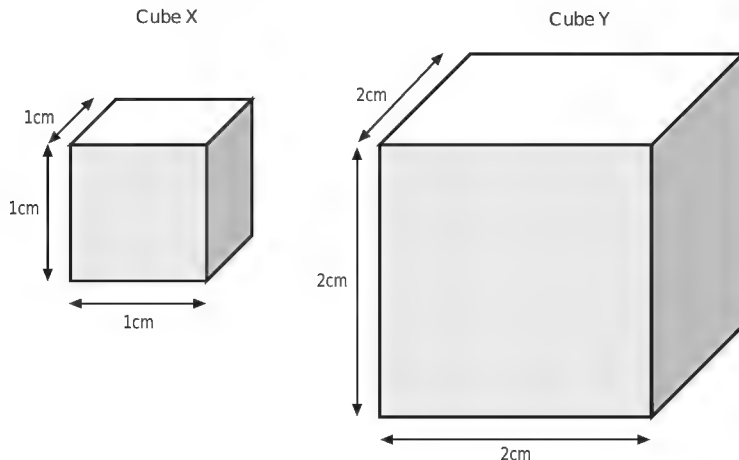
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(3)

**Total 11**

## Question 2

The diagrams below show two cubes with their dimensions.



- a) Calculate the surface area to volume ratio for the two cubes shown above.

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(2)

- b) With reference to size and your calculations in 2(a) explain the need for transport systems in complex multicellular organisms.

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(4)

- c) Name the main transport system and two specialised surfaces for exchange with the environment found in mammals

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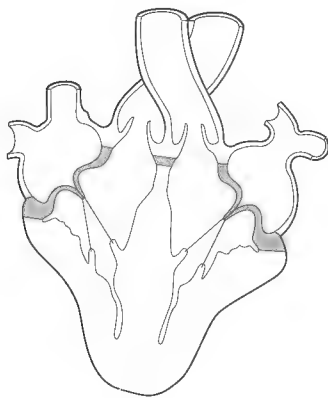
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(3)

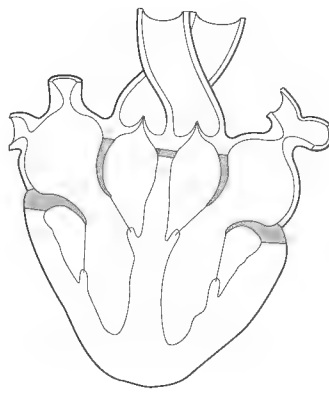
**Total 9**

### Question 3

Study the diagrams below showing the state of the heart at two stages in the cardiac cycle, and then answer the questions that follow.



X



Y

- a) i) Identify the diagram in which the ventricles are relaxed.

(1)

- ii) By means of a cross on one of the diagrams identify the chamber in which the pressure is highest.

(1)

- iii) By means of arrows on both of the diagrams above indicate the direction of the blood flow into and out of the heart.

(1)

- b) Describe what causes the pocket valves to shut at the point in the cardiac cycle illustrated by diagram Y.

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(3)

- c) i) Account for the difference between the position of the atrio-ventricular valves in diagrams X and Y.

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(3)

Question continued....



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ii) Describe how these valves are prevented from opening in the wrong direction.

(1)

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d) Explain the differences in the thickness of the heart chamber walls in relation to their functions.

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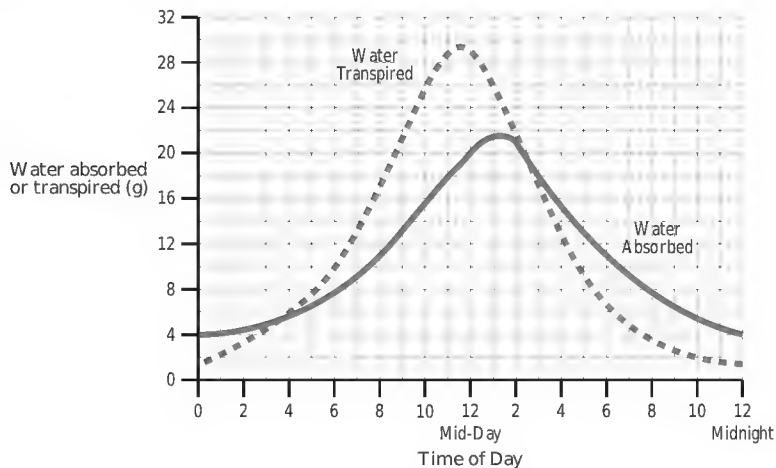
(3)

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**Total 13**

## Question 4

The relationship between the rate of water uptake by the roots of a plant and its transpiration rate over a 24 hour period, under natural conditions on a summer's day, is shown on the graph below.



- a) i) Identify the times when transpiration and water uptake reach their peaks.

(1)

- ii) Give one environmental factor other than temperature which reaches a peak near the time of maximum transpiration.

(1)

- iii) Explain the cause and effect relationship between the environmental factor peaking and the maximum transpiration rate.

(4)

Question continued....

- b) Describe the environmental conditions under which transpiration could continue at a high level (at least for a short period), but water uptake is reduced to a minimum.

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(2)

- c) Describe how the curves of the graphs shown at the start of the question help to explain the cohesion-tension mechanism of moving water through the xylem.

[illegible]

(8)

**Total 16**

### Question 5

- a) Within the first few days at high altitude a decrease in the blood plasma volume of a sea-level resident causes the red blood cell count to increase. Explain how this increase in red blood cells differs from the increase in red blood cells seen after a period of acclimatisation

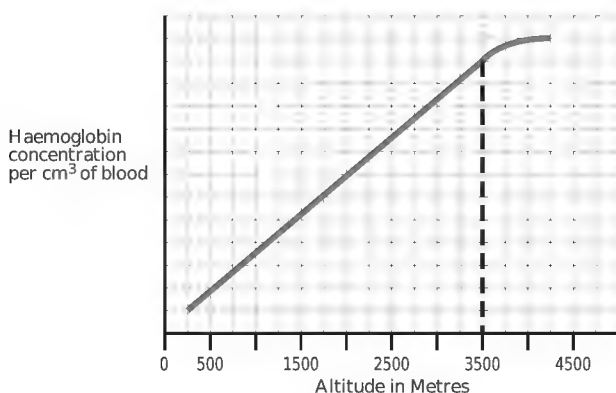
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(2)

- b) Study the graph of haemoglobin concentration in male residents at various altitudes and answer the following questions



- i) Explain the relationship between haemoglobin concentration and red blood cell count.

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(1)

- ii) Describe how the graph indicates that there is a limit to the altitude required to maximise gains in haemoglobin concentration.

---

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(1)

- c) Explain why endurance athletes undertake altitude training before competitions at sea level.

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(2)

Question continued....

- 
- d) i) Some endurance athletes also sleep in low pressure tents or tubes. Explain how this removes the need to travel to altitude for their training

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(2)

- ii) Other endurance athletes use the banned drug erythropoietin (EPO), which is the hormone that stimulates red blood cell production by the red bone marrow. They have red blood cell counts 30% higher than normal. Describe the danger associated with such high blood cell counts.

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(3)

**Total 11**

## Assessment Grid Biology

### 3: Transport

#### Year Set 2

| Specification Section   | Question Number |   |    |    |    |   |   |   |   | Total |
|-------------------------|-----------------|---|----|----|----|---|---|---|---|-------|
|                         | 1               | 2 | 3  | 4  | 5  | 6 | 7 | 8 | 9 |       |
| 3.1 Mammalian Transport | 11              | 9 |    |    | 11 |   |   |   |   | 31    |
| 3.2 Mammalian Heart     |                 |   | 13 |    |    |   |   |   |   | 13    |
| 3.3 Transport in Plants |                 |   |    | 16 |    |   |   |   |   | 16    |

Total 60

| Assessment Objective            | Question Number |   |    |   |   | Total |
|---------------------------------|-----------------|---|----|---|---|-------|
|                                 | 1               | 2 | 3  | 4 | 5 |       |
| <b>AO1</b>                      |                 |   |    |   |   |       |
| Knowledge with Understanding    | 8               | 3 | 10 | 7 | 7 | 35    |
| <b>AO2</b>                      |                 |   |    |   |   |       |
| Application/Analysis/Evaluation | 3               | 6 | 3  | 9 | 4 | 25    |

Total 60

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# Mark Schemes for Question Paper

## Biology

### 3 - Transport

#### Year Set 2

#### Instructions

; = 1 mark    / = alternative response

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#### Question 1

- a) Give brief descriptions of each of the following:
- i) blood plasma  
the fluid part of the blood dilute clear - yellow aqueous solution;  
about 60% of blood volume;  
containing soluble substances e.g. inorganic ions, and proteins; (3)
  - ii) tissue fluid  
that part of the plasma (minus plasma proteins) exuded through the capillary walls;  
as a result of blood (hydrostatic) pressure / water potential gradient; (2)
  - iii) lymph  
tissue fluid absorbed into lymphatic capillaries;  
contains lymphocytes;  
contains fats from lacteals in villi; (2)
- b) i) Describe one difference between a blood capillary and a lymphatic capillary.  
lymphatic capillary blind ending; (1)
- ii) Describe how the lymph is moved through the lymphatic system back to the circulation.  
contractions of surrounding skeletal muscles;  
massage thin walled lymph vessels;  
one way valves ensure one way flow; (3)

**Total 11**

## Question 2

The diagrams below show two cubes with their dimensions.

- a) Calculate the surface area to volume ratio for the two cubes shown above.

Cube X

$$\text{Surface area} = 6 \text{ cm}^2$$

$$\text{Volume} = 1 \text{ cm}^3$$

$$\text{Surface area to volume} = 6:1 = 6$$

Cube Y

$$\text{Surface area} = 24 \text{ cm}^2$$

$$\text{Volume} = 8 \text{ cm}^3$$

$$\text{Surface area to volume} = 24:8 = 3$$

(2)

- b) With reference to size and your calculations in 2(a) explain the need for transport systems in complex multicellular organisms.

the larger the organism the smaller the surface area to volume ratio;

surface exchanges substances with the environment;

volume must be supplied to and from surface;

transport systems needed to supply the relatively large volume from the relatively small surface;

(4)

- c) Name the main transport system and two specialised surfaces for exchange with the environment found in mammals

circulatory system;

lungs;

gut lining;

(3)

**Total 9**



### Question 3

Study the diagrams below showing the state of the heart at two stages in the cardiac cycle, and then answer the questions that follow.

Diagrams of heart at ventricular diastole and systole

- a) i) Identify the diagram in which the ventricles are relaxed. Y (1)
- ii) By means of a cross on one of the diagram identify the chamber in which the pressure is highest.  
Cross correctly identifying the left ventricle in diagram X (1)
- iii) By means of arrows on the two diagrams above indicate the direction of the blood flow into and out of the heart.  
Direction of flow of blood correctly shown on both diagrams. (1)
- b) i) Describe what causes the pocket valves to shut at the point in the cardiac cycle illustrated by diagram Y.  
by blood falling back down the blood vessels exiting the right and left ventricles (aorta and pulmonary arteries);  
as a result of the lower pressure in the empty ventricles;  
blood fills 'pockets';  
'pockets' block and shut the blood vessels; (3)
- c) i) Account for the difference between the position of the atrio-ventricular valves in diagrams X and Y.  
in Y blood has pushed atrio-ventricular (AV) valves open;  
as it was forced down by gravity and contraction of the atria;  
in X AV valves forced shut by contraction of ventricles forcing blood upwards;
- ii) Describe how these valves are prevented from opening in the wrong direction.  
prevented from opening the wrong way by tendon cords becoming taut;  
aided by muscles of ventricular wall exerting a downward pull on tendon cords; (1)
- d) Explain the differences in the thickness of the heart chamber walls in relation to their functions.  
atrial walls thinner the ventricles as only have to pump blood into ventricles;  
right ventricle thinner than left as only have to pump blood to lungs;  
left ventricle thicker as has to pump around body; (3)

**Total 13**

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## Question 4

The relationship between the rate of water uptake by the roots of a plant and its transpiration rate over a 24 hour period, under natural conditions on a summer's day, is shown in the graph below.

- a) i) Identify the times when transpiration and water uptake reach their peaks.  
transpiration around 12 and water uptake around 2 pm; (1)
- ii) Give one environmental factor other than temperature which reaches a peak near the time of maximum transpiration.  
light intensity; (1)
- iii) Explain the cause and effect relationship between the environmental factor peaking and the maximum transpiration rate.  
transpiration occurs mainly via the stomata;  
stomata open in the light;  
therefore the period of greatest stomatal opening and greatest transpiration;  
is period of maximum light intensity (4)
- b) Describe the environmental conditions under which transpiration could continue at a high level (at least for a short period) but water uptake is reduced to a minimum.  
dry hot conditions;  
soil water at a minimum; (2)
- c) Describe how the curves shown in the graph at the beginning of the question help to explain the cohesion-tension mechanism of moving water through the xylem.  
water uptake supplies plant and water loss;  
peak of transpiration occurs before that of water absorption;  
ie water loss greater than water gain;  
under conditions of high transpiration;  
therefore water in xylem under negative tension;  
as water pulled up by cohesion-tension;  
rather than pushed up by positive root pressure;  
in which case peaks would be in reverse order; (8)

**Total 16**

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## Question 5

- a) Within the first few days at high altitude a decrease in the blood plasma volume of a sea-level resident causes the red blood cell count to increase. Explain how this increase in red cells differs from the increase in red blood cells seen after a period of acclimatisation but has same total number of red cells in a smaller volume;  
increase after acclimatisation is an increase in total red cell number in normal volume; (2)
- b) Study the graph of haemoglobin concentration in male residents at various altitudes and answer the following questions
- i) Explain the relationship between haemoglobin concentration and red blood cell count.  
red cells contain haemoglobin therefore directly related; (1)
- ii) Describe how the graph indicates that there is a limit to the altitude required to maximise gains in haemoglobin concentration.  
curve levels off at 3500 m any further increase in altitude results in no further gains; (1)
- c) Explain why endurance athletes undertake altitude training before competitions at sea level.  
increased red cells / haemoglobin adapted to thinner air at altitude with lower  $pO_2$ ;  
when return to sea level air has higher  $pO_2$  and increased red cell count allows greater uptake giving greater oxygen delivery to muscles and greater aerobic performance; (2)
- d) i) Some endurance athletes also sleep in low pressure tents or tubes. Explain how this removes the need to travel to altitude for their training  
low pressure (hypobaric) tents and tubes mimic atmospheric conditions at altitude;  
body reacts in same way to reduced  $pO_2$ ; (2)
- ii) Other endurance athletes use the banned drug erythropoietin (EPO), which is the hormone that stimulates red blood cell production by the red bone marrow. They have red blood cell counts 30% higher than normal. Describe the danger associated with such high red cell counts.  
increased thickness (viscosity) of blood;  
difficulty in pumping blood around body reduces efficiency of circulation;  
danger of blockage of vessels and thrombosis; (3)

**Total 11**

# Biology

Examination Style  
Question Papers

**Year Set 3**

- 1 - Biology Foundation**
- 2 - Human Health & Disease**
- 3 - Transport**

Complete with Assessment Grids & Mark Schemes

**FELTHAM PRESS**

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# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### I - Biology Foundation Year Set 3

*Time allowed 1 hour 30 minutes*

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#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- about 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

### Question 1

- a)** What are plasmodesmata in the plant cell, and what is their role?

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(2)

- b)** Explain what is meant by the following terms with regard to the uptake of substances by cells:

- i) facilitated diffusion**

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(3)

- ii) active transport

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(3)

- c) Describe the pathways and barriers to their passage, that ions cross whilst being transported from an external bathing solution into the vacuolar sap. (In this question one mark is available for the quality of written communication.)

[illegible]

(7)

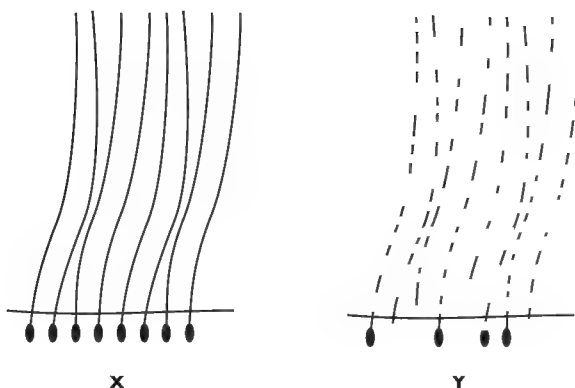
**Total 15**

## Question 2

- a) In the table below list three differences between the light (optical) and electron microscopes

| Light (optical) microscope | Electron microscope |
|----------------------------|---------------------|
|                            |                     |
|                            |                     |
|                            |                     |

(3)



- b) Drawing X represents cilia. Drawing Y represents the appearance of a section of cilia.

- i) Interpret and explain the difference in appearance between the two drawings.

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(3)

- ii) Name, and briefly describe a technique that can be used with an electron microscope to overcome some of the problems of interpretation seen in drawing Y of cilia above.

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(3)

- c) Give two examples of stages in the preparation of biological material for the electron microscope that could result in the distortion of the material.

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(2)

**Total 11**

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### Question 3

- a) i) What is the water potential of pure water at standard temperature and pressure?

\_\_\_\_\_  
\_\_\_\_\_ (1)

- ii) In relation to discussions about the tendency of water to move in systems, explain why water potential is preferred to the term 'concentration of water'.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

- iii) Name two factors to which the rate of osmosis is proportional.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (2)

- b) If a plant cell is placed in pure water, it eventually becomes fully turgid, the cellulose cell wall can expand no further, and so no more water enters the cell. Explain this process in terms of the effect of pressure on water potential.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (4)

- c) Sea water is more concentrated than the blood: in terms of osmosis explain why drinking sea water will only create greater thirst.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (2)

**Total 12**



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## Question 4

- a) A solution of unknown composition is tested with Benedict's solution, and a positive result is obtained.

i) Describe a positive result with the Benedict's test.

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(2)

ii) Explain why it would be wrong to deduce that the positive Benedict's test indicates that glucose is present.

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(3)

iii) Explain why it would not be correct to deduce from the positive Benedict's test that there were no disaccharides present in the solution.

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(3)

- b) i) Give the names of two proteins in the body.

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(2)

ii) Describe the Biuret test for proteins, and the appearance of a positive result.

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---

(3)

iii) Describe the problem in using the Biuret test for the disappearance of protein in an experiment investigating the rate of reaction of a protein digesting (protease) enzyme.

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(2)

**Total 15**

## Question 5

- a) The genetic code consists of a sequence of bases on a strand of DNA, and can be represented by a series of letters on a line as shown below

T A C C G T T C T A C C

- i) Describe what the letters represent, and give their names.

\_\_\_\_\_  
\_\_\_\_\_  
(2)

- ii) Draw a similar line with letters to represent the complementary strand of mRNA to the original DNA strand shown at the start of the question.

\_\_\_\_\_  
(1)

- b) The table below shows the genetic code on a strand of mRNA for selected amino acids.

| Amino acid | mRNA codons                                                                                           |
|------------|-------------------------------------------------------------------------------------------------------|
| Alanine    | GCA, GCC, GCG, GCU                                                                                    |
| Tryptophan | UGG                                                                                                   |
| Arginine   | AGA, AGG, CGA, CGC, CGG, CGU                                                                          |
| Lysine     | AAA, AAG                                                                                              |
| Methionine | AUG (also acts as the 'start' codon so that every polypeptide chain initially starts with methionine) |

Using the information in the table answer the following:

- i) write out the sequence of amino acids coded for by the original strand of DNA shown above in part (a) of the question,

\_\_\_\_\_  
\_\_\_\_\_  
(2)

- ii) explain what is meant by describing the genetic code as 'degenerate';

\_\_\_\_\_  
\_\_\_\_\_  
(2)

- c) Outline the general principles of gene manipulation by biotechnology, with reference to the synthesis of human insulin by bacteria. (In this question one mark is available for the quality of written communication.)

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
(8)

**Total 15**

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### Question 6

- a) Give a brief description of mitosis.

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(3)

- b) Name four specific sites where mitosis occurs in the adult body.

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(2)

- c) Explain how mitosis is involved in cancerous growths.

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(2)

- d) Name two factors that can increase the chances of cancerous growth.

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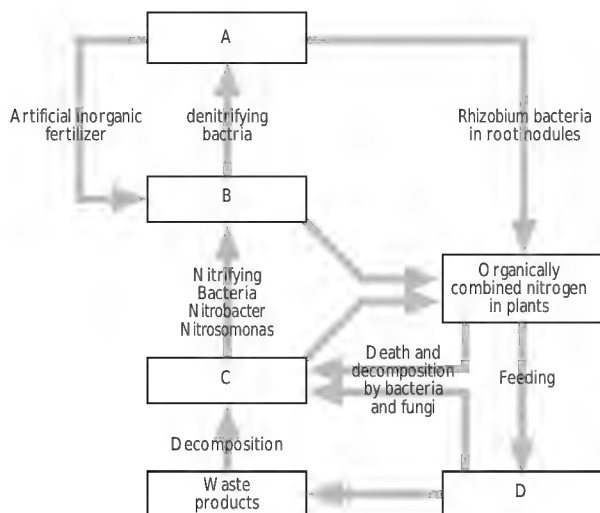
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(2)

**Total 9**

## Question 7

The flow chart below is a simple representation of the Nitrogen Cycle.



- a) Match the letters  
in the blank boxes with the most appropriate of the following:

Nitrates, Ammonium salts, Nitrogen in air, Animals.

- A** \_\_\_\_\_ (1)  
**B** \_\_\_\_\_ (1)  
**C** \_\_\_\_\_ (1)  
**D** \_\_\_\_\_ (1)

- b) i) Name a nitrogen containing compound found in both plants and animals.

\_\_\_\_\_  
 \_\_\_\_\_ (1)

Question continued...

- 
- ii) Plants with root nodules containing *Rhizobium* bacteria benefit from an increased synthesis of nitrogen containing compounds, describe two benefits that *Rhizobium* gains from the association.

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(2)

- c) Explain why there is so much nitrogen containing substance in:

- i) the faeces of animals.

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(3)

- ii) the urine of animals.

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(3)

**Total 13**

# Assessment Grid

## Biology

### I - Biology Foundation

#### Year Set 3

| Specification Section          | Question Number |    |    |    |    |   |    | Total |
|--------------------------------|-----------------|----|----|----|----|---|----|-------|
|                                | 1               | 2  | 3  | 4  | 5  | 6 | 7  |       |
| I.1 Cell Structure             | 15              |    |    |    |    |   |    | 15    |
| I.2 Biological Molecules       |                 | 11 |    |    |    |   |    | 11    |
| I.3 Enzymes                    |                 |    | 12 |    |    |   |    | 12    |
| I.4 Cell Membranes/Transport   |                 |    |    | 15 |    |   |    | 15    |
| I.5 Genetic Control of Protein |                 |    |    |    | 15 |   |    | 15    |
| I.6 Nuclear Division           |                 |    |    |    |    | 9 |    | 9     |
| I.7 Energy and Ecosystems      |                 |    |    |    |    |   | 13 | 13    |

Total 90

| Assessment Objective            | Question Number |   |   |   |    |   |   | Total |
|---------------------------------|-----------------|---|---|---|----|---|---|-------|
|                                 | 1               | 2 | 3 | 4 | 5  | 6 | 7 |       |
| AO1                             |                 |   |   |   |    |   |   |       |
| Knowledge with Understanding    | 8               | 5 | 6 | 9 | 10 | 7 | 7 | 52    |
| AO2                             |                 |   |   |   |    |   |   |       |
| Application/Analysis/Evaluation | 7               | 6 | 6 | 6 | 5  | 2 | 6 | 38    |

Total 90

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# Mark Schemes for Question Papers

## Biology

### I - Biology Foundation

#### Year Set 3

#### Instructions

; = 1 mark     / = alternative response

---

#### Question I

- a) What are plasmodesmata in the plant cell, and what is their role?  
cytoplasmic strands continuous between cells;  
transport of substances / communication; (2)
- b) Explain what is meant by the following terms with regard to the uptake of substances by cells:
- i) facilitated diffusion  
diffusion down a diffusion gradient;  
from higher concentration to lower concentration;  
speeded up/ made easier by the presence of special carriers in the membrane; (2)
- ii) active transport  
uptake against the prevailing diffusion gradient;  
from lower concentration to higher concentration;  
involving carriers in cell membrane;  
using energy from respiration / ATP; (3)
- c) Describe the pathways and barriers to their passage that ions cross whilst being transported from an external bathing solution into the vacuolar sap. (In this question one mark is available for the quality of written communication.)  
cellulose cell wall permeable;  
carries some electrical charges that may interfere with oppositely charged ions;  
cell surface membrane differentially / partially permeable;  
non-fat soluble substances pass less easily;  
cytoplasm itself acts as differentially / partially permeable barrier;  
tonoplast / vacuolar membrane differentially / partially permeable; (6)  
Q - legible text with accurate spelling, punctuation and grammar; (1)

**Total 15**

## Question 2

- a) In the table below list three differences between the light (optical) and electron microscopes

| Light (optical) microscope | Electron microscope                     |
|----------------------------|-----------------------------------------|
| Uses light                 | Uses a stream of electrons              |
| Light focussed by lenses   | Electrons focussed by magnets           |
| Objects observed directly  | Objects observed via fluorescent screen |

(3)

- b) Drawing X represents cilia. Drawing Y represents the appearance of a section of cilia.

- i) Interpret and explain the difference in appearance between the two drawings.

cilia elongated relatively long structures;

thin sections along their length only cut small lengths;

and rarely 'catch' the connection to the cell;

giving appearance of unattached segments;

(3)

- ii) Name and briefly describe a technique that can be used with an electron microscope to overcome the problem of interpretation seen in the drawing Y of cilia above.

scanning electron microscopy;

electrons 'scattered' / 'bounced' off of surface of specimen;

giving 3-D image;

(3)

- c) Give two examples of stages in the preparation of biological material for the electron microscope that could result in the distortion of the material.

dehydration;

very thin sections;

exposed in a vacuum;

stained with heavy metals;

(2)

**Total 11**



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### Question 3

- a) i) What is the water potential of pure water at standard temperature and pressure?  
0 (nought / zero) (1)
- ii) In relation to discussions about the tendency of water to move in systems, explain why water potential is preferred to the term 'concentration of water'.  
water is the solvent in which solutes dissolve;  
the term concentration normally refers to the solute;  
therefore the 'term concentration of water' implies it is acting as a solute  
water can move as a result of pressure which is nothing to do with concentration; (3)
- iii) Name two factors to which the rate of osmosis is proportional.  
temperature;  
surface area over which it is occurring; (2)
- b) If a plant cell is placed in pure water, it eventually becomes fully turgid, the contents of a fully turgid cell push out against the stretched cell wall which can expand no further and so no more water enters the cell. Explain this process in terms of the effect of pressure on water potential.  
the pressure inside the cell is raised above that in a non-turgid cell;  
an increase in pressure increases the water potential;  
reducing the water potential gradient to zero;  
so no more water enters the cell (4)
- c) Sea water is more concentrated than the blood, in terms of osmosis explain why drinking sea water will only create greater thirst.  
water will pass down its water potential gradient from the blood into the gut lumen;  
thus further dehydrating the blood; (2)

**Total 12**

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## Question 4

- a) A solution of unknown composition is tested with Benedict's solution and a positive result is obtained.
- i) Describe a positive result with the Benedict's test.  
green/ yellow/ red;  
precipitate; (2)
- ii) Explain why it would be wrong to deduce that glucose was present from the positive Benedict's test.  
Benedict's test is a test for reducing sugars;  
there are reducing sugars other than glucose;  
e.g. fructose, maltose, and lactose; (3)
- iii) Explain why it would not be correct to deduce from the positive result for the Benedict's test that there were no disaccharides present in the solution.  
sucrose is a non-reducing sugar;  
which gives a negative result with the Benedict's test;  
until after acid hydrolysis / boiling with acid and neutralisation;  
which breaks glycosidic bond releasing the reducing sugars glucose and fructose to give a positive result; (3)
- b) i) Give the names of two proteins in the body.  
any two proteins, e.g. keratin, collagen, haemoglobin; (2)
- ii) Describe the Biuret test for proteins, and the appearance of a positive result.  
add an equal volume of (5%) potassium hydroxide;  
add 2 drops of 1% copper sulphate;  
mauve or purple colour = positive; (3)
- iii) Describe the problem in using the biuret test for the disappearance of protein in an experiment investigating the rate of reaction of a protein digesting (protease) enzyme.  
enzymes are proteins;  
therefore will give positive result with the Biuret test;  
despite the disappearance of the substrate (2)

**Total 15**

## Question 5

- a) The genetic code consists of a sequence of bases on a strand of DNA, and can be represented by a series of letters on a line as shown below

T A C C G T T C T A C C

- i) Describe what the letters represent, and give their names.

nitrogenous bases / nucleotides;

thymine, adenine, cytosine, guanine

(2)

- ii) Draw a similar line with letters to represent the complementary strand of mRNA to the original DNA strand shown at the start of the question.

A U G G C A A G A U G G

(1)

- b) The table below shows the genetic code on a strand of mRNA for selected amino acids.

Using the information in the table answer the following:

- i) write out the sequence of amino acids coded for by the original strand of DNA shown above in part (a) of the question

methionine-alanine-arginine-tryptophan

(2)

- ii) explain what is meant by describing the genetic code as 'degenerate';

some / most amino acids coded for by more than one triplet codon;

e.g. tryptophan and methionine only have one, but alanine has 4, arginine has 6

lysine has 2

(2)

- c) Outline the general principles of gene manipulation by biotechnology, with reference to the synthesis of human insulin by bacteria. (In this question one mark is available for the quality of written communication.)

by isolating mRNA from beta cells of pancreas;

using reverse transcriptase to recreate gene (length of DNA) for human insulin;

circular plasmid DNA removed from bacteria;

plasmids cut open with restriction enzymes;

human insulin DNA spliced in using ligase enzymes;

engineered plasmids reintroduced into bacteria;

bacteria multiply and produce human insulin;

(7)

Q - clear, well organised using specialist terms;

(1)

**Total 15**

---

## Question 6

- a) Give a brief description of mitosis.  
division of the nucleus in the cell cycle;  
in which chromosome number is maintained;  
giving genetically identical daughter nuclei; (3)
- b) Name four specific sites where mitosis occurs in the adult body.  
any four e.g.  
germinative layer of the skin;  
bone marrow;  
gut lining;  
uterus; (2)
- c) Explain how mitosis is involved in cancerous growths.  
uncontrolled mitotic cell division;  
gives exponential growth/ doubling of daughter cells by compound interest; (2)
- d) Name two factors that can increase the chances of cancerous growth.  
any two e.g.  
radioactive particles;  
electromagnetic radiation / X rays / gamma rays / UV light;  
carcinogenic chemicals; (2)

**Total 9**

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## Question 7

The flow chart below is a simple representation of the Nitrogen Cycle.

- a) Match the letters in the blank boxes with the most appropriate of the following:

Nitrites, Nitrobacter, Nitrosomonas, Nitrates

- A - Nitrogen in air; (1)  
B - Nitrates; (1)  
C - Ammonium salts; (1)  
D - Animals; (1)

- b) i) Name a type of nitrogen containing compound found in both plants and animals.

amino acid / protein / DNA / RNA / ATP etc; (1)

- ii) Plants with root nodules containing Rhizobium bacteria benefit from an increased synthesis of nitrogen containing compounds; describe two benefits that Rhizobium gains from the association.

protection from competition ie antibiotics;

Krebs cycle intermediates / organic compounds;

growth factors; (2)

- c) Explain why there is so much nitrogen containing substance in:

- i) the faeces of animals,

inefficiencies of digestion;

nitrogen containing substances in plant matter;

nitrogen containing substances in bacteria from gut; (3)

- ii) the urine of animals.

animals cannot store excess protein / amino acids;

therefore excess in diet metabolised to nitrogen containing waste products e.g. urea;

also from general turnover of proteins in metabolism; (3)

**Total 13**

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# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### 2 - Human Health and Disease

#### Year Set 3

*Time allowed 1 hour 30 minutes*

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#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 90.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 75 of the marks, and extended parts questions about 15 marks.
- About 54 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

---

## Question 1

**a)** Explain, with one example of each, what is meant by the following terms relating to disease.

**i)** epidemic

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(2)

**ii)** pandemic

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(2)

**iii)** endemic

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(2)

**b) i)** Briefly explain the reasons for collecting health statistics.

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(4)

**ii)** Explain how the two modern phenomena of global warming, and cheap rapid international travel, are altering the global patterns of disease distribution.

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(4)

**Total 14**

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## Question 2

A balanced diet is essential for the correct utilisation of energy. Insufficient carbohydrate quickly leads to the removal of amino acids from the proteins of the muscles, their transport to the liver, and conversion to glucose. The glucose is then oxidised as a source of energy for the muscles from which the amino acids were originally removed.

- a) In the light of the information in the passage above give an explanation of the phrase that 'dieting makes you fat'.

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(4)

- b) i) Explain the consequences of protein deficiency.

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(3)

- ii) Pure protein deficiency is rare, but there is a whole spectrum of deficiencies between pure calorie deficiency and pure protein deficiency, known as protein-energy malnutrition or PEM. Give the two prime causes of PEM.

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(2)

- iii) Explain, with regard to PEM, why 'breast is best' when it comes to infant feeding.

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(2)

- c) Two conditions relating to nutrition and associated with developed societies are anorexia nervosa and obesity

- i) List three features that characterise anorexia nervosa.

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(3)

- ii) State the percentage of body fat usually quoted for the average adult male and female, and the limits above which a male and female would be considered obese.

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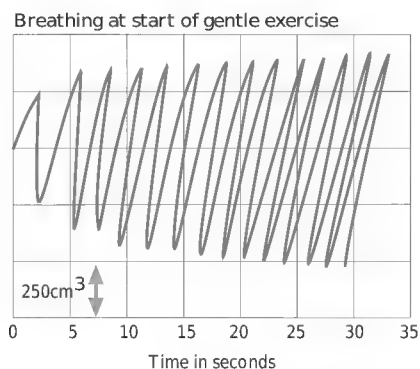
(2)

**Total 16**



### Question 3

The diagram below is of a trace from a respirometer measuring the breathing of a person at rest who then starts exercising at a rate which causes them to start breathing more heavily and quickly.



- a) i) Ventilation of the lungs is by tidal flow in and out of a single air tube the trachea. What are the main disadvantages of this method of ventilating a respiratory system?

\_\_\_\_\_  
 \_\_\_\_\_ (2)

- ii) Explain the meaning of the term tidal volume, and from the diagram above, determine the tidal volume at rest.

\_\_\_\_\_  
 \_\_\_\_\_ (2)

- b) i) Explain the term vital capacity.

\_\_\_\_\_  
 \_\_\_\_\_ (2)

- ii) Explain why the tidal volume cannot equal the vital capacity during exercise.

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_ (3)

- c) Explain why all the extra oxygen absorbed as a result of an increase in ventilation and cardiac output during an exercise such as running, is not available for the improvement of performance.

\_\_\_\_\_  
 \_\_\_\_\_ (2)

**Total 11**

#### Question 4

Two major components of tobacco smoke are nicotine and carbon monoxide.

- a) Carbon monoxide combines irreversibly with haemoglobin and 200 times more readily than oxygen. Explain the effect of this on smokers.

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(3)

- b) Nicotine is a dependence-producing drug which mimics the effects of, and stimulates the release of the hormones adrenaline and noradrenaline, both of which have wide ranging direct effects on the body, including constriction of blood vessels and increase in heart rate.

- i) Describe the effects of nicotine on blood pressure.

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(2)

- ii) Explain how these effects on blood pressure could lead to a stroke.

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(3)

- c) Nicotine also increases the concentration of fatty acids in the blood, and the 'stickiness' of the blood platelets.

- i) Describe how these changes increase the risk of atherosclerosis.

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(3)

- ii) Describe how atherosclerosis can lead to heart attacks and strokes. (In this question one mark is available for the quality of written communication.)

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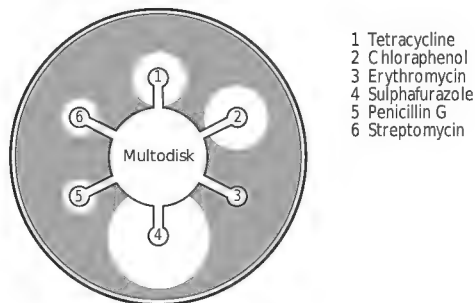
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(7)

**Total 18**

### Question 5

Study the diagram below which illustrates the effect of different anti-bacterial agents on a culture of bacteria grown on an agar plate. The sterile paper 'multodisk' has 6 arms and the tip of each is impregnated with a different anti-bacterial agent. Anti-bacterial agents 1, 3, 5, 6, are antibiotics.



- a) i) Describe and explain the appearance of the agar plate.

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(5)

- ii) Explain why the type of bacterial culture grown on the agar plate is significant.

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(2)

- b) Using your observations of the experiment above and your own knowledge, outline the role of antibiotics in the treatment of infectious disease. (In this question one mark is available for the quality of written communication.)

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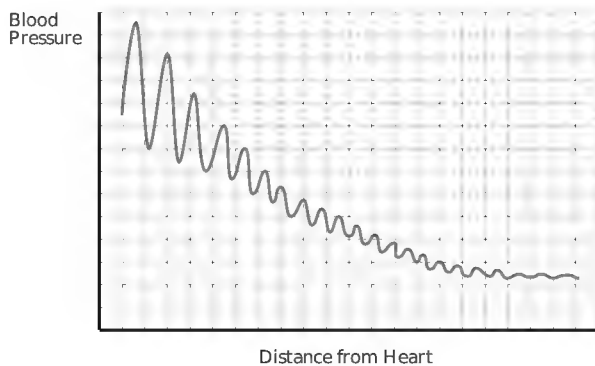
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(7)

**Total 14**

### Question 6

The graph below shows the relationship between blood pressure and the distance from the heart.



Describe and explain the shape of the curve on the graph above.

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**Total 5**

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### Question 7

**a)** With regard to the acquisition of immunity, explain what is meant by the following.

**i)** Natural passive immunity in the unborn child.

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(2)

**ii)** Artificial passive immunity

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(2)

**iii)** Natural active immunity.

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(1)

**(iv)** Artificial active immunity.

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(2)

**b)** With regard to the acquisition of immunity, explain why breast feeding is to be preferred to bottle feeding.

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(2)

**c)** With regard to their composition, list the different type of vaccine that may be used against infectious microorganisms. Give an example of each type of vaccine you have mentioned.

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(3)

**Total 12**

## Assessment Grid Biology

### 2: Human Health and Disease

#### Year Set 3

| Specification Section         | Question Number |    |    |    |    |   |    |   |   | Total |
|-------------------------------|-----------------|----|----|----|----|---|----|---|---|-------|
|                               | 1               | 2  | 3  | 4  | 5  | 6 | 7  | 8 | 9 |       |
| 2.1 Health and Disease        | 14              |    |    |    |    |   |    |   |   | 14    |
| 2.2 Diet                      |                 | 16 |    |    |    |   |    |   |   | 16    |
| 2.3 Gas Exchange and Exercise |                 |    | 11 |    |    | 5 |    |   |   | 16    |
| 2.4 Smoking and Disease       |                 |    |    | 18 |    |   |    |   |   | 18    |
| 2.5 Infectious Diseases       |                 |    |    |    | 14 |   |    |   |   | 14    |
| 2.6 Immunity                  |                 |    |    |    |    |   | 12 |   |   | 12    |

Total 90

| Assessment Objective            | Question Number |    |   |    |   |   |   | Total |
|---------------------------------|-----------------|----|---|----|---|---|---|-------|
|                                 | 1               | 2  | 3 | 4  | 5 | 6 | 7 |       |
| AO1                             |                 |    |   |    |   |   |   |       |
| Knowledge with Understanding    | 7               | 10 | 9 | 7  | 7 | 2 | 9 | 51    |
| AO2                             |                 |    |   |    |   |   |   |       |
| Application/Analysis/Evaluation | 7               | 6  | 2 | 11 | 7 | 3 | 3 | 39    |

Total 90

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# Mark Schemes for Question Paper

## Biology

### 2 - Human Health and Disease

#### Year Set 3

#### Instructions

; = 1 mark    / = alternative response

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#### Question 1

- a) Explain, with one example of each, what is meant by the following terms relating to disease.
- i) epidemic  
rapid spread of a disease through a population;  
e.g. influenza; (2)
  - ii) pandemic  
an epidemic spread on an international scale;  
e.g. AIDS; (2)
  - iii) endemic  
of a disease found constantly among people in a particular area;  
e.g. malaria; (2)
- b) i) Briefly explain the reasons for collecting health statistics.
- to monitor epidemics;
  - to allocate priorities;
  - for preventative strategies;
  - for predictive purposes; (4)
- ii) Explain how the two modern phenomena of global warming, and cheap rapid international travel are altering the global patterns of disease distribution.
- increase in temperature in temperate climates especially winter;
  - extends range of several diseases and / or their vectors;
  - rapid international travel triggers pandemics;
  - establishing diseases in new areas; (4)

**Total 14**

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## Question 2

A balanced diet is essential for the correct utilisation of energy. Insufficient carbohydrate quickly leads to the removal of amino acids from the proteins of the muscles, their transport to the liver, conversion to glucose, and its subsequent oxidation as a source of energy for the muscles from which the amino acids were removed.

- a) In the light of the information in the passage above give an explanation of the phrase that 'dieting makes you fat'.
- the loss of muscle protein during the shortage of calories;  
reduces the metabolising muscle mass;  
reducing energy demand;  
when supply returns to previous normal levels excess energy stored as fat; (4)
- b) i) Explain the consequences of protein deficiency.
- insufficient amino acids, essential ones particularly;  
to maintain normal protein 'turnover';  
and repair of damaged tissues; (3)
- ii) Pure protein deficiency is rare, but there is a whole spectrum of deficiencies between pure calorie deficiency and pure protein deficiency, known as protein-energy malnutrition or PEM. Give the two prime causes of PEM.
- poverty;  
ignorance; (2)
- iii) Explain with regard to PEM why 'breast is best' when it comes to infant feeding.
- breast milk ideal balance of nutrients for infant plus antibodies;  
commercial preparations expensive and tendency to overdilute to make last; (2)
- c) Two conditions relating to nutrition and associated with developed societies are anorexia nervosa and obesity
- i) List three features that characterise anorexia nervosa.
- profound fear of becoming fat;  
excessive loss of weight;  
amenorrhoea; (3)
- ii) State the percentage of body fat for the average adult male and female, and the limits above which a male and female would be considered obese.
- 12 and 25  
20 and 30 (2)

**Total 16**



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### Question 3

The diagram below is of a trace from a respirometer measuring the breathing of a person at rest who then starts exercising at a rate which causes them to start breathing more heavily and quickly.

- a) i) Ventilation of the lungs is by tidal flow in and out of a single air tube the trachea. What are the main disadvantages of this method of ventilating a respiratory system?

stationary air results close to the respiratory surface;

diffusion gradients of respiratory gases decrease;

(2)

- ii) Explain the meaning of the term tidal volume, and from the diagram above, determine the tidal volume at rest.

the amount of air moved over the lungs in a normal breathing cycle;

500 cm<sup>3</sup>

(2)

- b) i) Explain the term vital capacity.

the greatest volume of air that can be moved over the lungs;

with the greatest possible breath in and out;

(2)

- ii) Explain why the tidal volume cannot equal the vital capacity during exercise.

rate of breathing too high;

to move vital capacity;

in the time available;

(3)

- c) Explain why all the extra oxygen absorbed as a result of an increase in ventilation and cardiac output during an exercise such as running is not available for the improvement of performance.

the respiratory muscles / diaphragm and inter-costal muscles;

take up a proportion of the increase;

(2)

**Total 11**

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## Question 4

Two major components of tobacco smoke are nicotine and carbon monoxide.

- a) Carbon monoxide combines irreversibly with haemoglobin and 200 times more readily than oxygen. Explain the effect of this on smokers.  
prevents combination with oxygen;  
reduces transport of oxygen;  
impairs mental and physical performance; (3)
- b) Nicotine is a dependence-producing drug which mimics the effects of, and stimulates the release of, two hormones adrenaline and noradrenaline, both of which have wide ranging direct effects on the body including constriction of blood vessels and increase in heart rate.
- i) Describe the effects of nicotine on blood pressure.  
constriction of blood vessels increases resistance to flow of blood;  
increase in heart rate increases cardiac output;  
increases in cardiac output and resistance to flow of blood increases blood pressure. (2)
- ii) Explain how these effects on blood pressure could lead to a stroke.  
increased blood pressure can burst damaged walls of smaller blood vessels'  
if this occurs in those supplying the brain;  
supply of blood to part of brain interrupted leading to brain damage in that area; (3)
- b) Nicotine also increases the concentration of 'fats' in the blood, and the 'stickiness' of the blood platelets.
- i) Describe how these changes increase the risk of atherosclerosis.  
atherosclerosis a degenerative disease of the artery walls characterised by build up of fatty plaques;  
fats and sticky platelets increase tendency of blood to clot;  
depositing patches of fibrin on the walls of blood vessels to provide start of atherosclerosis;  
fatty plaques built up from 'fats' in the blood; (3)
- ii) Describe how atherosclerosis can lead to heart attacks and strokes. (In this question one mark is available for the quality of written communication.)  
fatty plaques may block vessels directly;  
interrupting flow to heart (heart attack) and brain (stroke);  
rough surfaces of plaques precipitate the formation of an internal clot / thrombosis which block vessels;  
plaques may weaken walls which burst / haemorrhage;  
or stretch giving an aneurysm / dilatation;  
which may rupture;  
or cause thrombosis;  
which may break free as a floating clot or embolism and block vessels; (6)  
Q - legible text with accurate spelling, punctuation and grammar; (1)

**Total 18**

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## Question 5

Study the diagram illustrating the effect of a sterile paper 'multodisc' with the tip of each arm impregnated with a different anti-bacterial agent on an agar plate on which bacteria are growing. Anti-bacterial agents 1, 3, 5, 6, are antibiotics.

- a) i) Describe and explain the appearance of the agar plate.  
the experimental culture is spread evenly over the plate;  
except around discs 1, 2, 4, 5, and 6 around these are clear circular patches;  
due to diffusion of the anti-bacterial agents from the discs;  
killing the bacteria in these areas;  
except one ( no. 3) to which the bacteria must be resistant;  
variation in size of other circles due to variation in bacterial resistance; (5)
- ii) Explain why the type of bacterial culture grown on the agar plate is significant.  
different bacteria have different susceptibilities to different antibiotics;  
e.g. penicillin ineffective against TB;  
cannot extrapolate from reaction of one bacterium to reaction of another; (2)
- b) Using your observations of the experiment above and your own knowledge outline the role of antibiotics in the treatment of infectious disease. (In this question one mark is available for the quality of written communication.)  
antibiotics not universally effective against all infectious diseases / viruses;  
broad-spectrum antibiotics effective against many;  
but may alter balance of useful microorganisms leading to infections as a result of dominance of resistant strains e.g. thrush in women;  
resistance may also develop in the originally sensitive target organism;  
through over prescription;  
combination therapies needed for resistant strains;  
course of treatment must be completed; (6)  
Q - clear, well organised using specialist terms; (1)

**Total 14**

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## Question 6

The graph shows the relationship between the blood pressure and the distance from the heart.

Describe and explain the shape of the curve on the graph above.

series of peaks and troughs;

decreasing in size with distance from the heart;

overall curve decreasing with distance from the heart;

heart contracts pushing blood into arteries then relaxes;

arteries expand to accommodate and recoil when heart relaxes;

pulse of artery wall matches heart rate exactly;

force / pressure of blood decreases with distance;

as a result of friction / resistance to flow;

less resistance to flow in capillaries;

**Total 5**

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## Question 7

- a) With regard to the acquisition of immunity, explain what is meant by the following.
- i) Natural passive immunity in the unborn child.  
the acquisition of ready made antibodies in a natural way;  
across the placenta from the mother to the foetus; (2)
  - ii) Artificial passive immunity  
the acquisition of ready made antibodies in an artificial way / by injection;  
when infection is too dangerous / acute to wait for development of natural immunity; (2)
  - iii) Natural active immunity.  
antibodies produced as a result of natural exposure to the disease causing agent; (1)
  - iv) Artificial active immunity.  
vaccination / immunisation;  
antibodies produced as a result of artificial exposure;  
to a harmless dose of the disease agent; (2)
- b) With regard to the acquisition of immunity, explain why breast feeding is to be preferred to bottle feeding.  
suckling infant gains maternal antibodies in colostrum ('first' milk) of mother;  
not present in bottle feeding; (2)
- c) With regard to their composition, list the different types of vaccine that may be used against infectious microorganisms. Give an example of each type of vaccine you have mentioned.  
living / attenuated live pathogen e.g. T.B. / Measles / Polio  
dead pathogen e.g. Cholera / Typhoid;  
toxin of pathogen e.g. Diphtheria / Tetanus (3)

**Total 12**

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# Examination Style Question Papers

## Biology

Name: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

### 3 - Transport

#### Year Set 3

*Time allowed 60 minutes*

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#### Instructions:

- Answer all the questions in the spaces provided.

#### Information

- Mark allocations are shown in brackets.
- The maximum mark for this paper is 60.
- Questions have both structured parts and parts which require more extended answers.
- Structured parts of questions carry about 50 of the marks, and 10 marks for the extended answer.
- about 36 of the marks will be for knowledge and understanding; and the remainder will be for application of knowledge and understanding, analysis and evaluation;
- Quality of Written Communication will be assessed where an answer involves a piece of extended writing.
- Scientific terminology should be used where appropriate.
- Calculators may be used.

## Question 1

The table below shows the levels of oxygen and carbon dioxide (in mm Hg) in the alveolar air and in the blood.

|                | Blood in pulmonary artery | Air in the alveoli | Blood in pulmonary vein |
|----------------|---------------------------|--------------------|-------------------------|
| Oxygen         | 40                        | 98                 | 96                      |
| Carbon dioxide | 46                        | 40                 | 40                      |

- a) i) Referring to the figures in the table, describe the exchange of oxygen and carbon dioxide between the air in the alveoli and the blood.

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(4)

- ii) Describe how the concentration gradients illustrated in the table could be increased (steepened).

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(3)

- b) Describe how the alveoli in the lungs are adapted for gaseous exchange.

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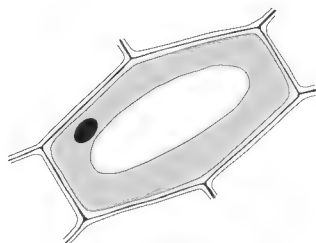
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(4)

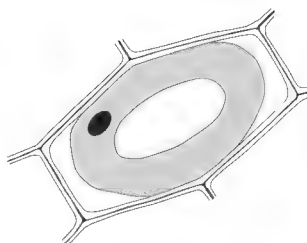
**Total 11**

## Question 2

The diagrams below show two plant cells, each bathed in a different external solution.



Cell A



Cell B

- a) i) Name the cell which is most turgid.

\_\_\_\_\_ (1)

- ii) Explain the importance of turgid cells in leaves

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (2)

- b) i) Describe the uptake of water from the soil by plant root hairs.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

- ii) Explain in terms of the water potential of plant cells and their surroundings why leaves wilt in conditions of water shortage.

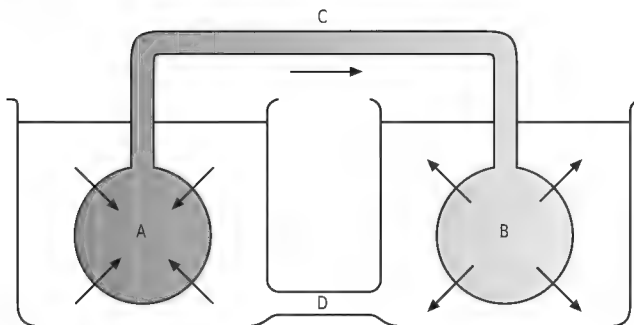
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_ (3)

**Total 9**



### Question 3

The diagram below shows a simple model used to demonstrate the mass flow hypothesis for the translocation of sugars in the phloem.



a) Identify which part of the model represents:

i) the phloem;

\_\_\_\_\_  
 \_\_\_\_\_ (1)

ii) the xylem;

\_\_\_\_\_  
 \_\_\_\_\_ (1)

b) For the movement of water and dissolved sugars to be maintained from chamber A to chamber B sugars must be continually added to A and removed from B. Identify the regions equivalent to A and B and the processes that achieve these changes in the plant.

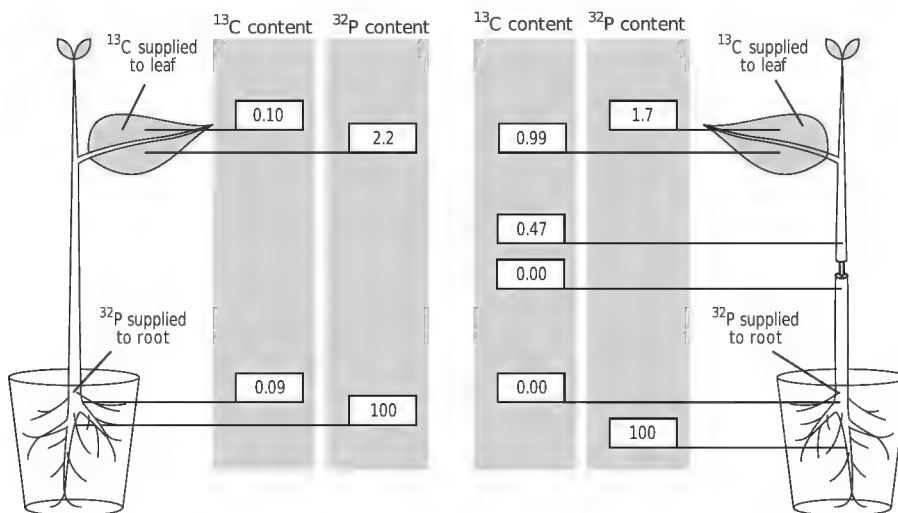
\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_ (4)

c) Ringing experiments remove all tissues external to the xylem in a woody stem and lead to the accumulation of sugars above the ring. Explain how this helps to demonstrate that translocation of sugars occurs in the phloem.

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_ (2)

*Question continued...*

- d) The diagrams below represent the results of ringing experiments on plants, the leaves of which were exposed to radioactive  $^{13}\text{C}\text{O}_2$  and the roots of which were exposed to radioactive  $^{32}\text{P}$ .



- i) Name the forms in which  $^{13}\text{C}$  and  $^{32}\text{P}$  would have been supplied to the plant.

\_\_\_\_\_  
 \_\_\_\_\_ (1)

- ii) By reference to the diagrams explain how this experiment demonstrates the role of phloem in the translocation of sugars.

\_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_ (4)

Question continued...

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e) Explain how the following observations could be used as evidence **against** the mass flow hypothesis for the translocation of sugars in the phloem.

i) Only young phloem tissue showing cytoplasmic streaming is active in the transport of organic materials (translocation).

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(2)

ii) Metabolic inhibitors such as, temperatures above and below the optimum, respiratory poisons such as cyanide, and anaerobic conditions, all result in a slowing of the rate of translocation.

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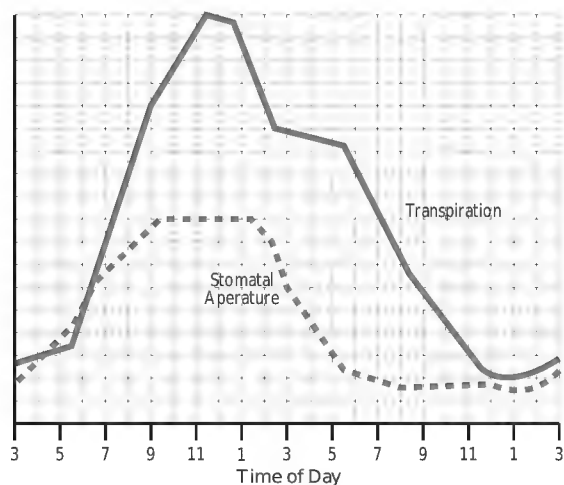
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(3)

**Total 18**

## Question 4

The graph below shows the relationship between stomatal opening (aperture) and the rate of transpiration from a plant leaf over a 24 hour period under natural conditions on a summer's day.



- a) i) Describe the general relationship between the stomatal aperture and the rate of transpiration.

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(2)

- ii) Explain how the transpiration rate can rise and fall independent of the stomatal aperture.

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(3)

- b) Some plants e.g. desert plants, close their stomata during the day and open them at night. Explain the advantage of this pattern of opening and closing to these plants.

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(2)

Question continued...

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- c) Describe how the leaves of xerophytes can be adapted to reduce water loss by transpiration.

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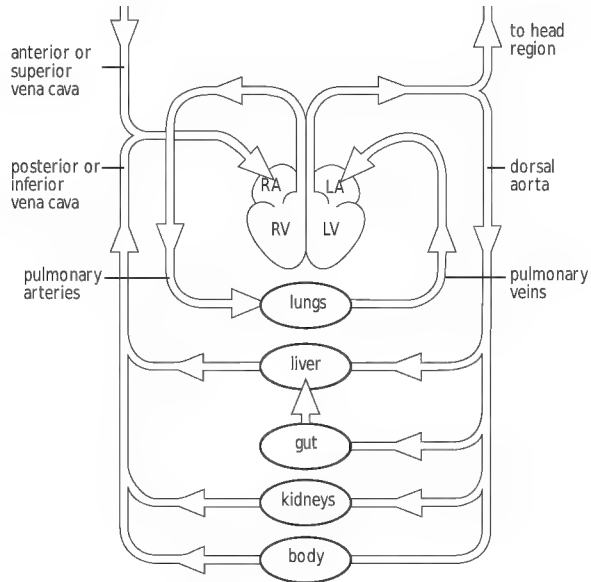
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(8)

**Total 15**

## Question 5

The diagram below represents the mammalian circulatory system.



- a) By reference to the diagram above and your own knowledge explain why the mammalian circulatory system is said to be a closed double circulation.

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(4)

- b) Explain why a double circulation is necessary to maintain an efficient blood supply to the body.

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(3)

**Total 7**

## Assessment Grid Biology

### 3: Transport

#### Year Set 3

|                         | Question Number |   |    |    |   |   |   |   |   |       |
|-------------------------|-----------------|---|----|----|---|---|---|---|---|-------|
| Specification Section   | 1               | 2 | 3  | 4  | 5 | 6 | 7 | 8 | 9 | Total |
| 3.1 Mammalian Transport | 11              |   |    |    |   |   |   |   |   | 11    |
| 3.2 Mammalian Heart     |                 |   |    |    | 7 |   |   |   |   | 7     |
| 3.3 Transport in Plants |                 | 9 | 18 | 15 |   |   |   |   |   | 42    |

Total 60

|                                 | Question Number |   |    |    |   |       |
|---------------------------------|-----------------|---|----|----|---|-------|
| Assessment Objective            | 1               | 2 | 3  | 4  | 5 | Total |
| AO1                             |                 |   |    |    |   |       |
| Knowledge with Understanding    | 7               | 5 | 8  | 13 | 3 | 36    |
| AO2                             |                 |   |    |    |   |       |
| Application/Analysis/Evaluation | 4               | 4 | 10 | 2  | 4 | 24    |

Total 60

# Mark Schemes for Question Paper

## Biology

### 3 - Component 01: Transport

#### Year Set 3

#### Instructions

; = 1 mark / = alternative response

#### Question 1

The table below shows the levels of oxygen and carbon dioxide (in mm Hg) in the alveolar air and in the blood.

|                | Blood in pulmonary artery | Air in the alveoli | Blood in pulmonary vein |
|----------------|---------------------------|--------------------|-------------------------|
| Oxygen         | 40                        | 98                 | 96                      |
| Carbon dioxide | 46                        | 40                 | 40                      |

- a) i) Referring to the figures in the table, describe the exchange of oxygen and carbon dioxide between the air in the alveoli and the blood.
- oxygen in blood in pulmonary artery at 40.0 lower than air in the alveoli at 98;  
diffusion gradient from alveoli to blood;  
therefore oxygen diffuses into blood;  
carbon dioxide in pulmonary artery at 46.0 higher than air in the alveoli at 40;  
therefore carbon dioxide diffuses out of blood; (4)
- ii) Describe how the concentration gradients illustrated in the table could be increased (steepened).
- by increased activity;  
therefore increased oxygen consumption;  
and increased carbon dioxide production;  
only slightly by increased ventilation; (4)
- b) i) Describe how the alveoli in the lungs are adapted for gaseous exchange.
- large number of small structures increase total surface area in a given volume;  
corrugations caused by pulmonary capillaries between alveoli increase surface area of individual alveoli;  
epithelial cells thin for short diffusion distance between air and blood; (3)

**Total 11**



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## Question 2

The diagrams below show two plant cells, each bathed in a different external solution.

- a) i) Name the cell which is the most turgid.

Cell A

(1)

- ii) Explain the importance of turgid cells in leaves  
cells push out against each other;  
support leaf ;

(2)

- b) i) Describe the uptake of water from the soil by plant root hairs.

if soil solution more dilute than root hair cell contents;

water enters root hair cells by osmosis;

the steepness of the water potential gradient between the two determines the rate of water uptake;

(3)

- ii) Explain in terms of the water potential of plant cells and their surroundings why leaves wilt in conditions of water shortage.

when water in short supply to leaves transpiration greater than water supply;

mesophyll cells of leaf become less turgid (more flaccid) especially spongy mesophyll;

flaccid mesophylls no longer support leaves which wilt;

(3)

**Total 9**

### Question 3

The diagram below shows a simple model used to demonstrate the mass flow hypothesis for the translocation of sugars in the phloem.

- a) Identify which part of the model represents:
- i) the phloem;  
C (1)
  - ii) the xylem;  
D (1)
- b) For a movement of water and dissolved sugars to be maintained from chamber A to chamber B sugars must be continually added to A and removed from B. Identify the regions equivalent to A and B and the processes that achieve these changes in the plant.
- A - leaves  
carrying out photosynthesis;  
B - roots;  
carrying out respiration; (4)
- c) Ringing experiments remove all tissues external to the xylem in a woody stem and lead to the accumulation of sugars above the ring. Explain how this helps to demonstrate that translocation of sugars occurs in the phloem.
- tissues outside of the cambium in a woody stem includes the phloem;  
accumulation of sugars above the ring shows that in absence of phloem translocation stops; (2)
- d) The diagrams below represent the results of ringing experiments on plants, the leaves of which were exposed to radioactive  $^{13}\text{C}$  and the roots of which were exposed to radioactive  $^{32}\text{P}$ .
- i) Name the forms in which  $^{13}\text{C}$  and  $^{32}\text{P}$  would have been supplied to the plant.  
carbon dioxide and phosphate ions; (1)
  - ii) By reference to the diagrams explain how this experiment demonstrates the role of phloem in the translocation of sugars.  
in unringed plant  $^{13}\text{C}$  content of leaf 0.10 and reaches root (as sucrose) 0.09;  
in ringed plant none reaches roots;  
 $^{32}\text{P}$  transport in xylem from roots to leaves only slightly down in ringed plant;  
indicating that upward transport unhindered by ringing ie no general damage to whole stem; (4)
- e) Explain how the following observations could be used as evidence **against** the mass flow hypothesis for the translocation of sugars in the phloem.
- i) Only young phloem tissue showing cytoplasmic streaming is active in the transport of organic materials (translocation).  
no need for cytoplasmic streaming in mass flow mechanism;  
which is a purely physical mechanism; (2)
  - ii) Metabolic inhibitors such as, temperatures above and below the optimum, respiratory poisons such as cyanide, and anaerobic conditions all result in a slowing of the rate of translocation.  
metabolic inhibitors inhibit enzyme activity including respiratory pathways;  
would appear that slowing of energy supply as ATP slows translocation;  
mass flow mechanism does not require any active input of energy; (3)

**Total 18**

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## Question 4

The graph below shows the relationship between stomatal opening (aperture) and the rate of transpiration from a plant leaf over a 24 hour period under natural conditions on a summer's day.

- a) i) Describe the general relationship between the stomatal aperture and the rate of transpiration.  
as one rises so does the other;  
with their highest values around midday;  
and their lowest values in the dark; (2)
- ii) Explain how the transpiration rate can rise and fall independent of the stomatal aperture.  
once stomata opened maximally no longer limiting factor;  
rise and fall of transpiration affected by environmental factors which become limiting;  
change in temperature / change in humidity / change in air movements; (3)
- b) Some plants e.g. desert plants, close their stomata during the day and open them at night.  
Explain the advantage of this pattern of opening and closing to these plants.  
in hot dry conditions danger of excess water loss by transpiration;  
via stomata therefore shut during day therefore must open at night for carbon dioxide uptake; (2)
- c) Describe how the leaves of xerophytes can be adapted to reduce water loss by transpiration.  
reduced surface area e.g. needles in pine;  
spines in cacti;  
'hairy' surface;  
leaf rolling protects stomata;  
thick waxy cuticle;  
stomata sunken in pits and/or grooves;  
stomata restricted to lower surface of leaf;  
abscission layer activates in dry periods; (8)

**Total 15**

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## Question 5

The diagram below represents the mammalian circulatory system.

- a) By reference to the diagram above and your own knowledge explain why the mammalian circulatory system is said to be a closed double circulation.

closed as blood completes the circulation within a closed system of vessel;

via arteries capillaries and veins from heart back to heart;

double as passes through heart twice on each complete circulation of the body;

heart to lungs, lungs to heart, heart to body and back to heart;

(4)

- b) Explain why a double circulation is necessary to maintain an efficient blood supply to the body.

blood has to pass through two sets of capillaries on each complete circulation;

without double circulation through heart;

blood pressure and flow could not support efficient metabolism;

(3)

**Total 7**

# Biology



- 1 - Biology Foundation**
- 2 - Human Health & Disease**
- 3 - Transport**

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# Slide Masters

## Contents List

- 1 - Biology Foundation
  - 1 Magnification and resolution
  - 2 Ultra sound scan of fetus
  - 3 Prokaryotic cell
  - 4 T.S. lung
  - 5 T.S. leaf
  - 6 Monosaccharides and disaccharides
  - 7 Polysaccharide
  - 8 Structure of triglyceride
  - 9 Phospholipid
  - 10 Phospholipids and the bilayer
  - 11 Amino acid structure
  - 12 Amino acid structure and peptide bond
  - 13 Secondary and tertiary structure of proteins
  - 14 Structure of haemoglobin
  - 15 Activation energy
  - 16 Enzyme substrate complex
  - 17 Effects of temperature, pH, enzyme and substrate concentrations on enzyme activity
  - 18 Graphs of enzyme inhibition
  - 19 Phospholipids and the bilayer (repeat of No. 10)
  - 20 Fluid mosaic model
  - 21 Diffusion in the alveolus
  - 22 Cation exchange at root hairs
  - 23 Structure of DNA and semi-conservative replication (this should be the title of OHT 23 in the Topic Guides)
  - 24 Base sequence - gene code
  - 25 Codons for amino acids
  - 26 Transcription
  - 27 Translation
  - 28 Genetic engineering
  - 29 Root tip squash
  - 30 Normal human karyotype A
  - 31 Human karyotype analysed into homologous pairs (male)
  - 32 Normal human karyotype B
  - 33 Human karyotype analysed into homologous pairs (female)
  - 34 Pyramid of biomass
  - 35 Nitrogen cycle
- 2 - Human Health
  - 36 WHO definition of health
  - 37 Patterns of disease
  - 38 Dietary reference value curves
  - 39 RNIs for vitamins
  - 40 Increasing levels of obesity

- 41 Coronary heart disease risk factors
- 42 Coronary heart disease risk factors questions
- 43 Spirometer trace
- 44 Blood pressure and distance from the heart
- 45 Oxygen debt
- 46 Fast and slow twitch fibres
- 47 Chicken muscles
- 48 Risk of bronchitis with smoking
- 49 Risk of lung cancer with smoking
- 50 Heart disease risks factors chart (repeat of No. 41)
- 51 Questions on heart disease risk factors chart (repeat of No. 42)
- 52 Worldwide distribution of coronary heart disease (CHD)
- 53 WHO definition of health (repeat of No. 36)
- 54 Map of malarious regions
- 55 Malaria life cycle
- 56 Structure of AIDS virus
- 57 Worldwide distribution of AIDS
- 58 Bacterial colonies on agar plates
- 59 Stem cells and the origin of phagocytes and lymphocytes
- 60 Phagocytes and lymphocytes
- 61 B-lymphocyte action - sequence of events
- 62 T-lymphocyte action - sequence of events
- 63 Primary and secondary immune responses
- 64 Antibody structure
- 65 Antibodies binding pathogens together
- 3 - Transport
- 66 Cubes 2cm and 1cm sides
- 67 Structure of arteries and veins as seen under the light microscope
- 68 Structure of typical capillary
- 69 Blood components
- 70 Diagram showing relationship between blood and lymph
- 71 Diagram of alveoli and associated capillaries (repeat of No. 21)
- 72 Normal dissociation curve
- 73 Bohr shift
- 74 Fetal haemoglobin dissociation curve
- 75 Diagram of heart structure
- 76 Mammalian heart
- 77 Closed double circulation diagram
- 78 Graph/chart of cardiac cycle
- 79 Diagram of electrical activity in heart
- 80 ECG trace
- 81 Distribution of vascular tissues in stem, root and leaf
- 82 Xylem and phloem T.S. and L.S.
- 83 Structure of vessels in xylem
- 84 Structure of sieve tube elements and companion cells in phloem
- 85 Diagram of turgid and plasmolysed cells
- 86 Ringing experiments (note that this is not an autoradiograph)

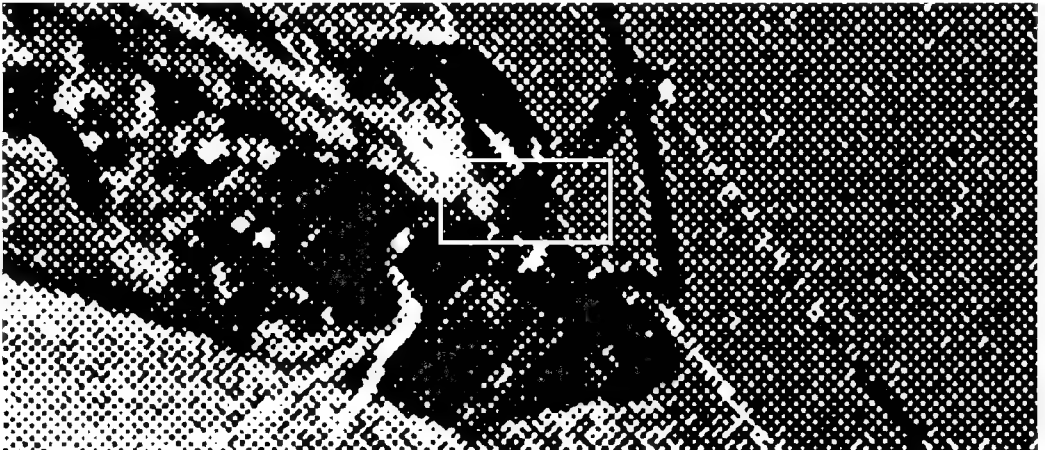
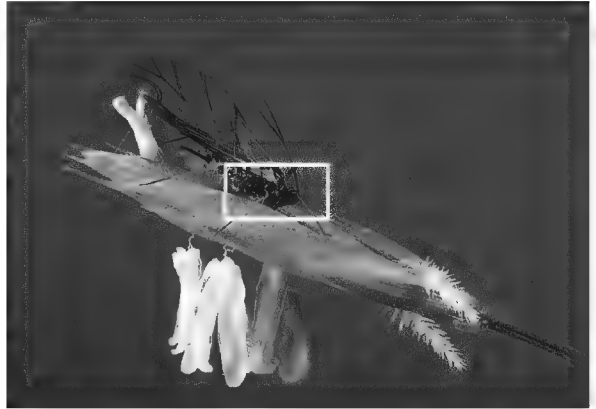
NB (Topic Guide Page 50: OHT TB in England and Wales not provided)

The image is composed of dots.

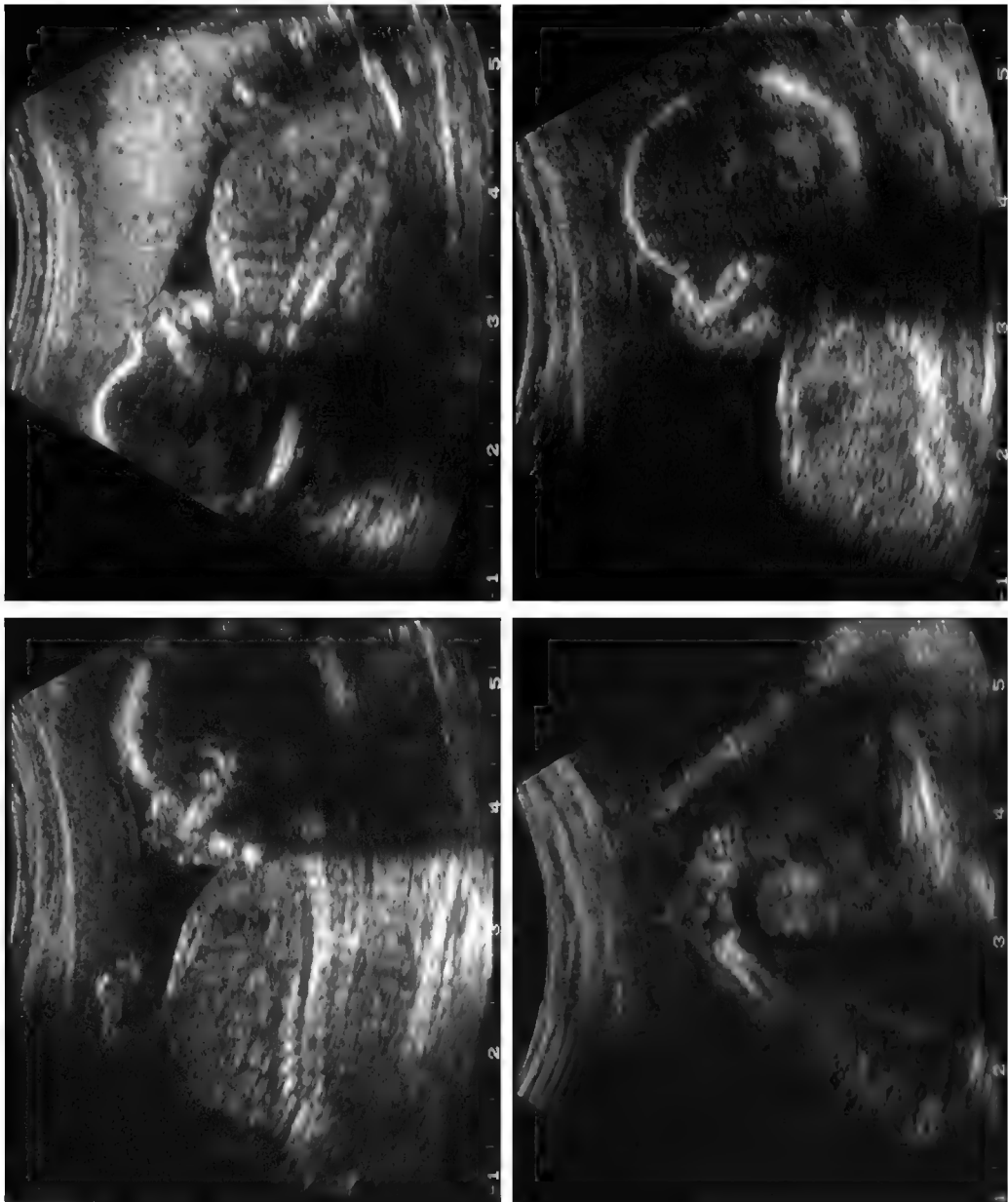
No amount of **magnification** will reveal any more detail or information ie; nothing more can be **resolved**.

**Magnification** increases the apparent size of an object.

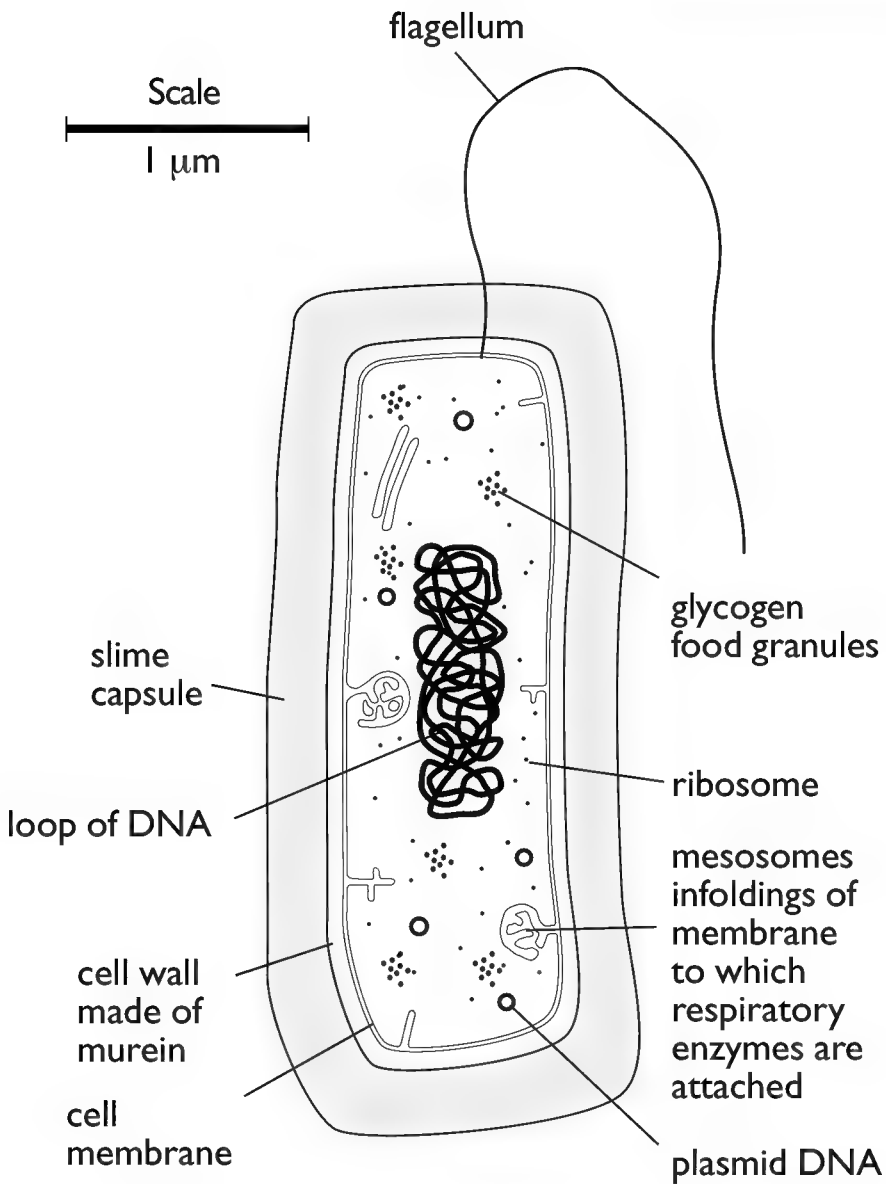
**Resolution** is the ability of an optical system to distinguish between adjacent points.



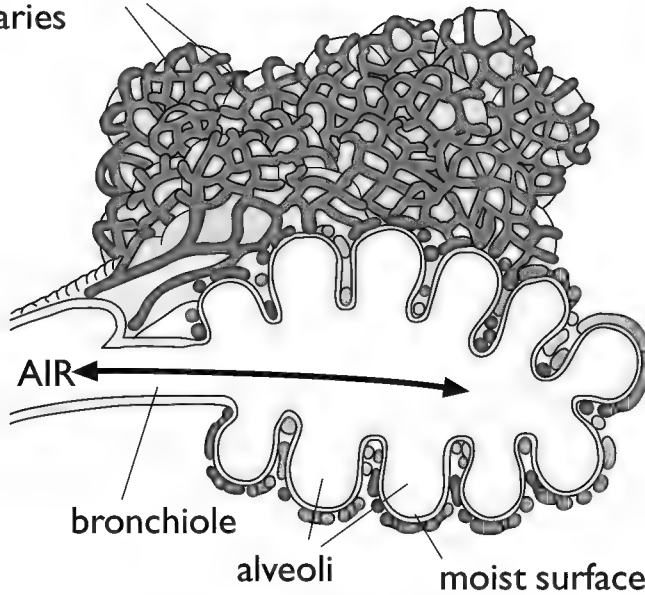




## Prokaryotic cell



alveoli surrounded  
by capillaries



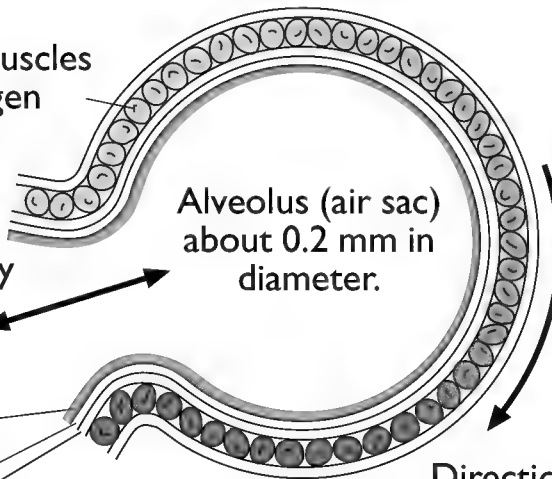
red blood corpuscles  
picking up oxygen

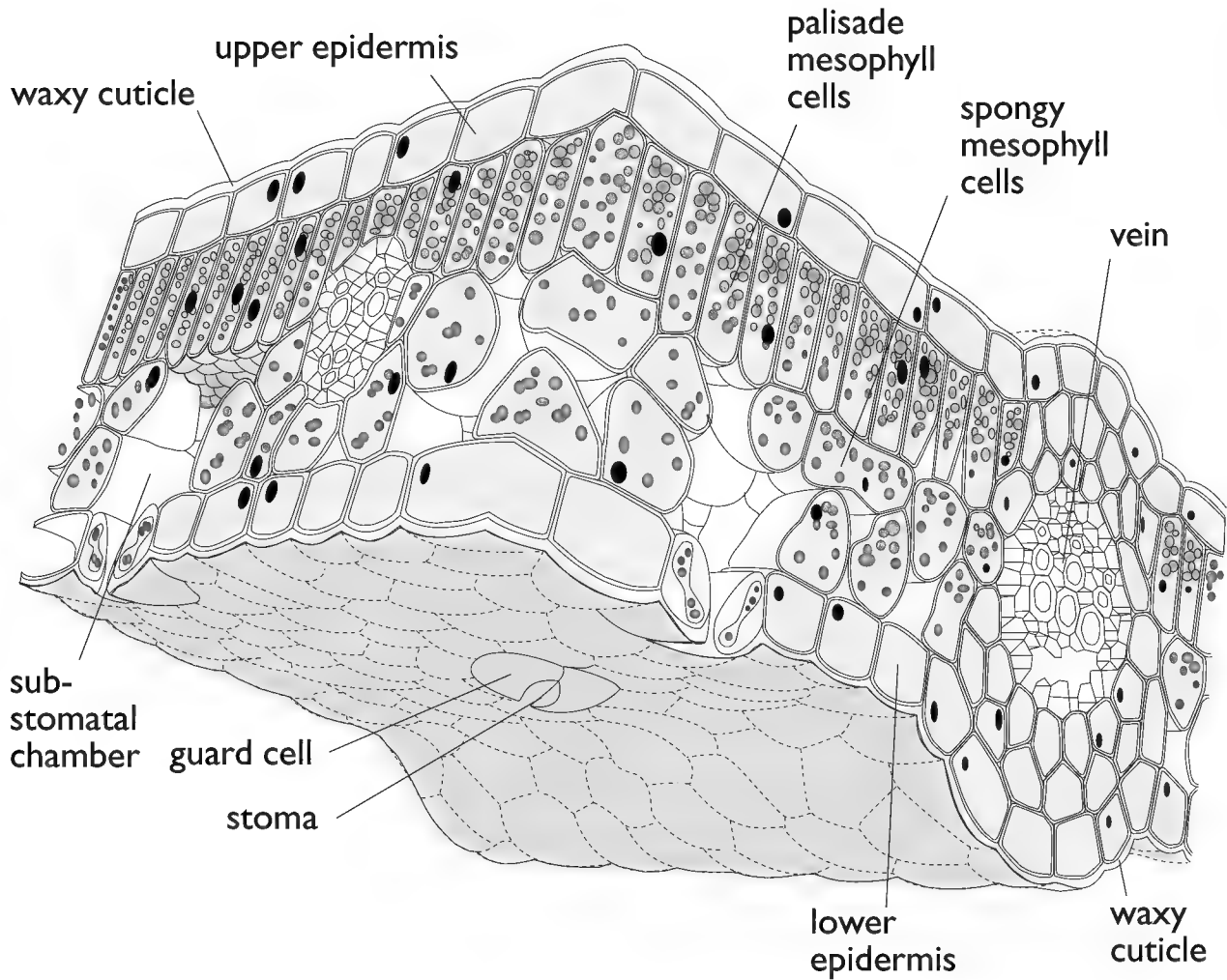
Air exchange by  
breathing  
movements

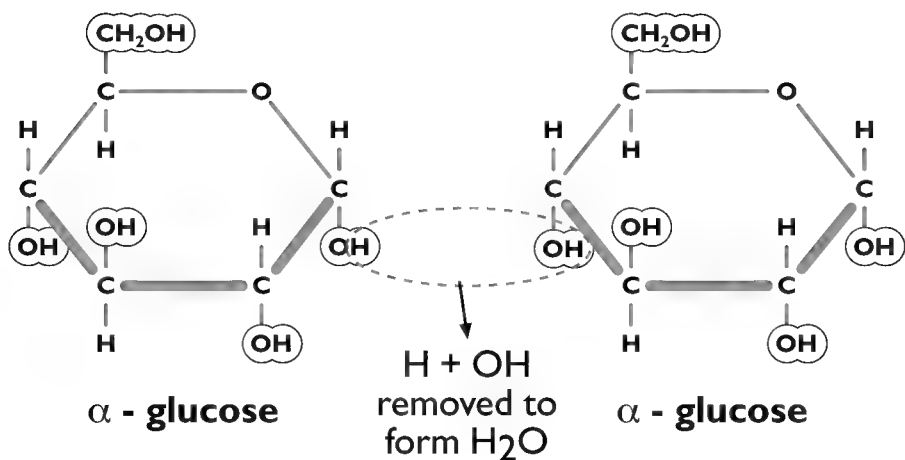
moist surface  
very thin walls  
of alveolus  
and capillary

Alveolus (air sac)  
about 0.2 mm in  
diameter.

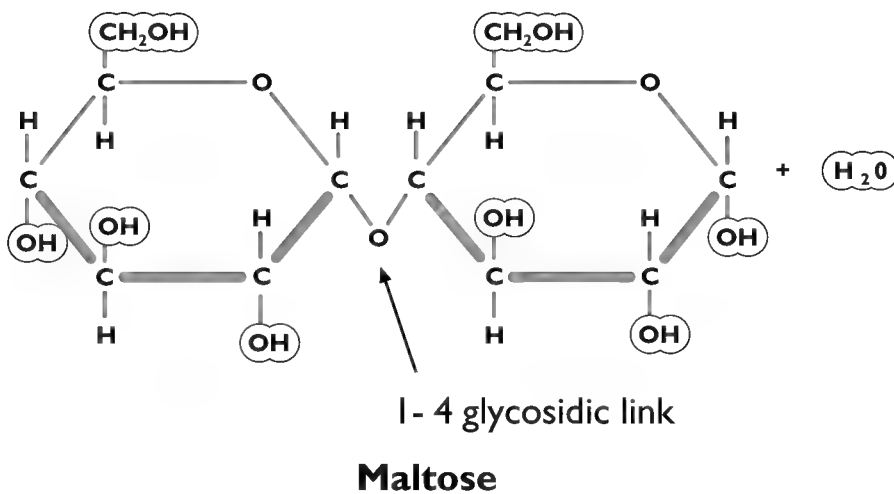
Direction of  
blood flow.



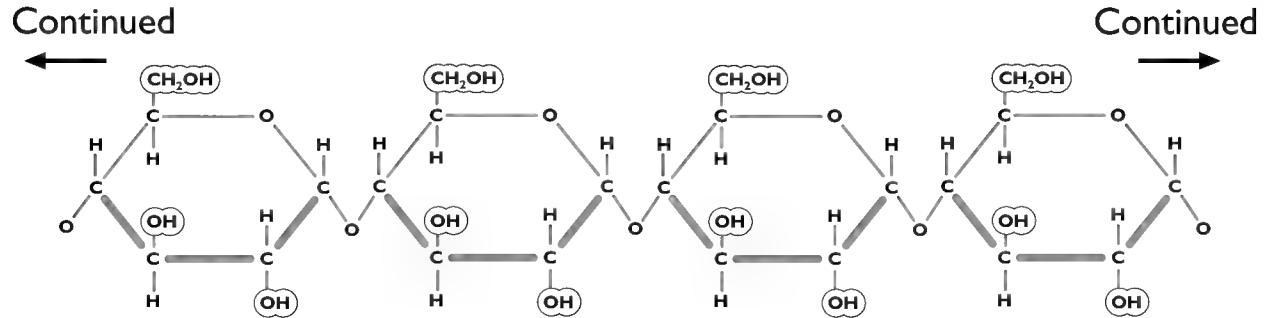




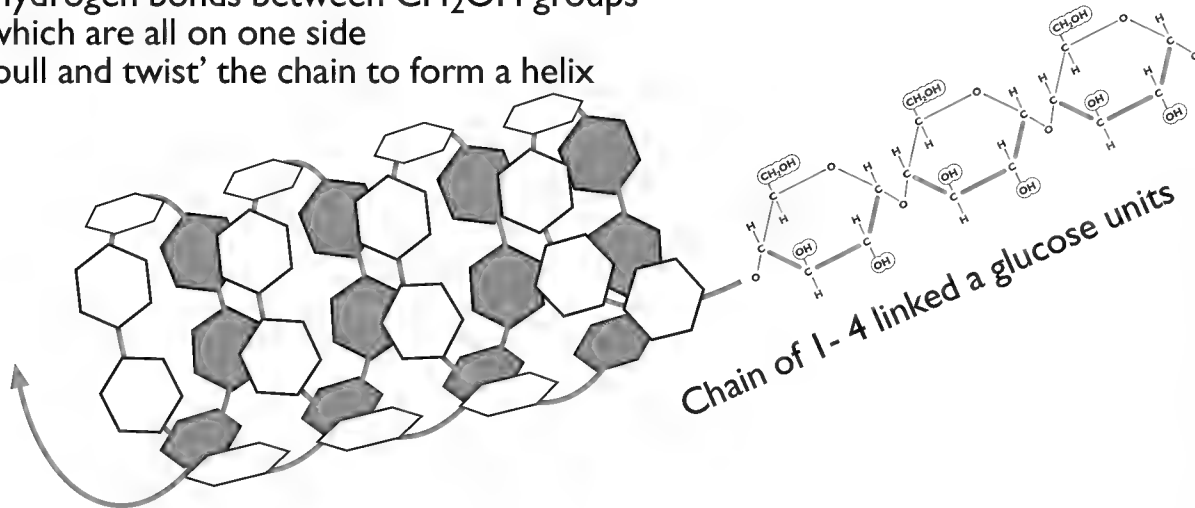
Hydrolysis  $\rightleftharpoons$  Condensation  
Enzyme catalysed reaction  
requiring energy from ATP



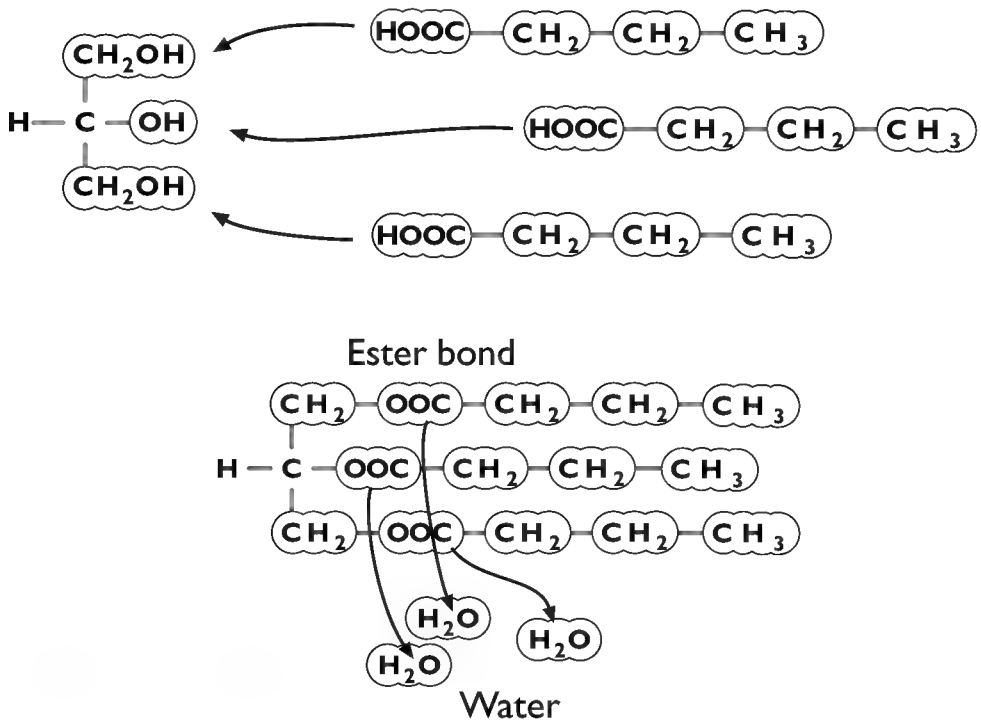
## Part of amylose molecule chain



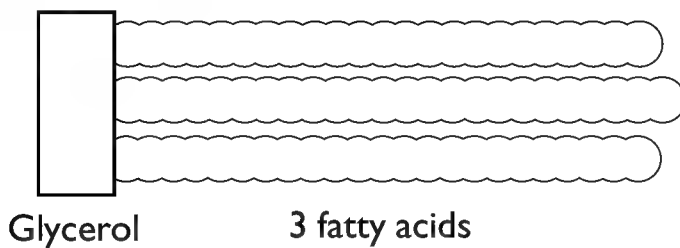
Hydrogen bonds between  $\text{CH}_2\text{OH}$  groups  
which are all on one side  
'pull and twist' the chain to form a helix

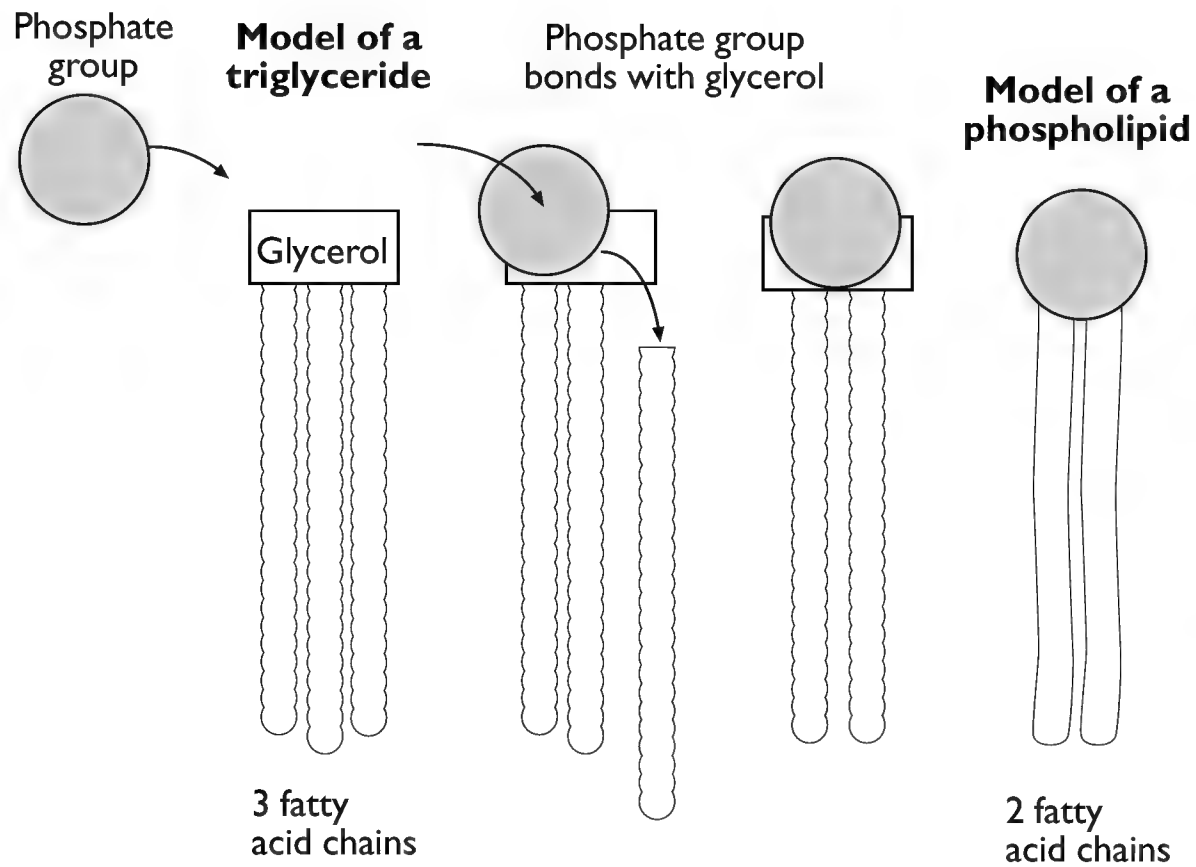


## Structure of triglyceride

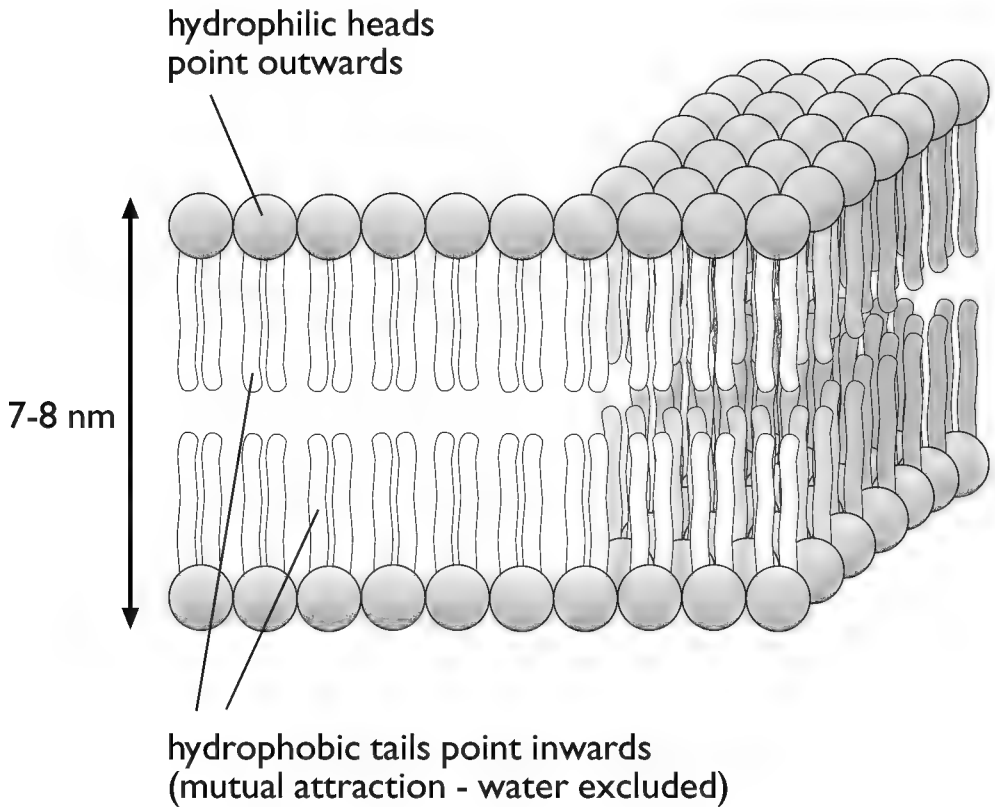


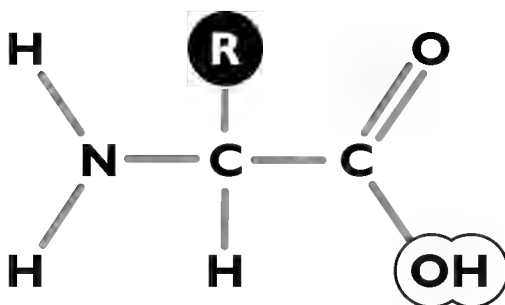
## Model of a triglyceride



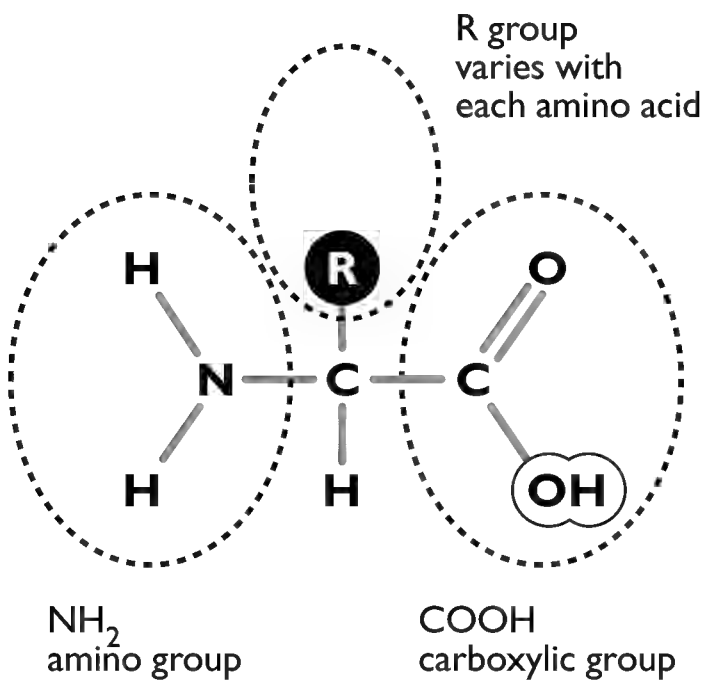




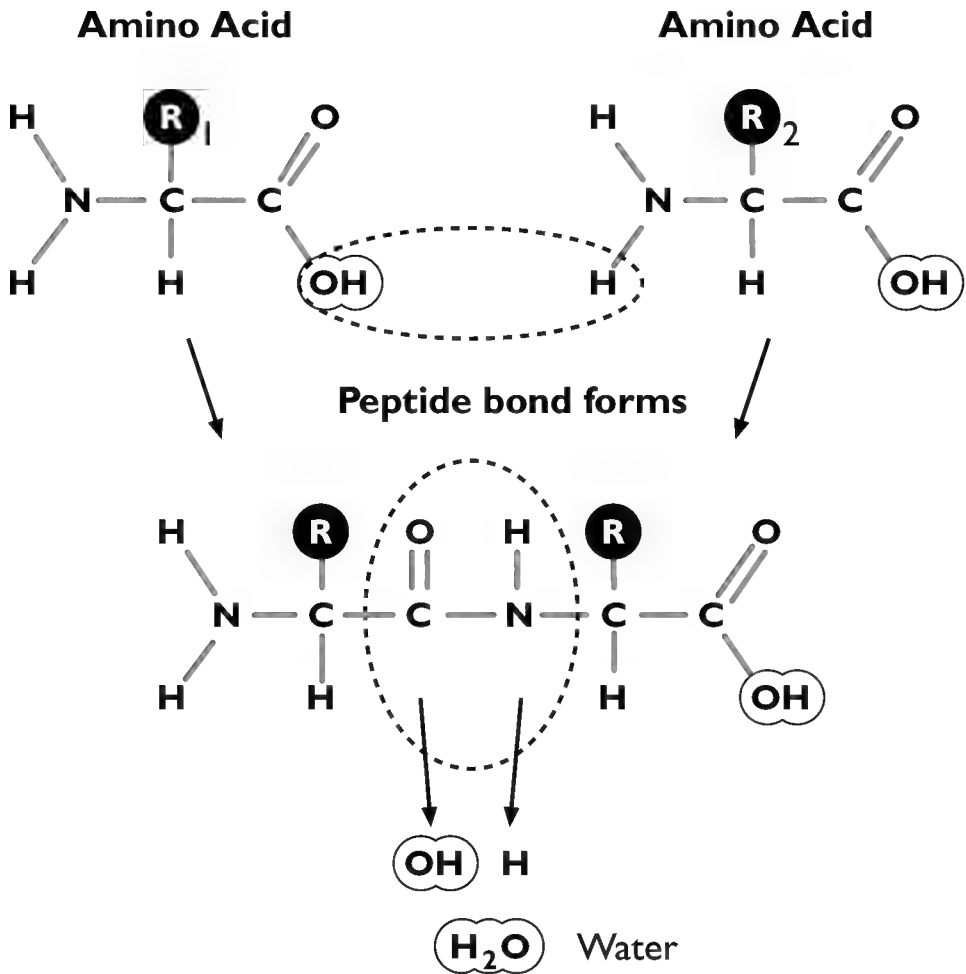




**Amino Acid**

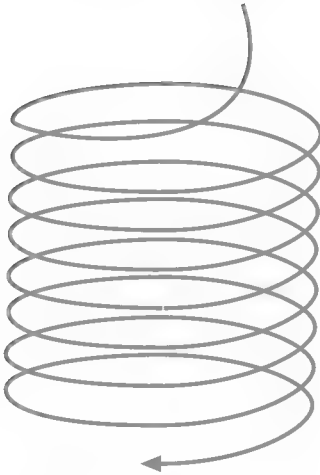


## Amino acid structure and peptide bond

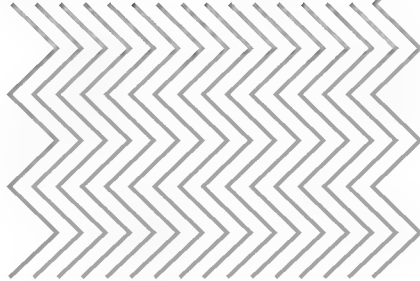


## Secondary structure of proteins

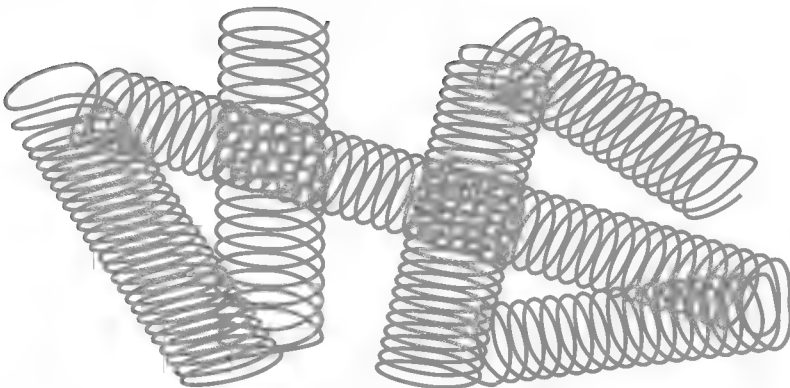
In an alpha helix hydrogen bonds 'pull' molecule chain into a spiral structure



In a beta sheet hydrogen bonds hold and align molecule chains side by side. Angle of bonds in each chain are as a consequence perfectly aligned forming 'pleats'.



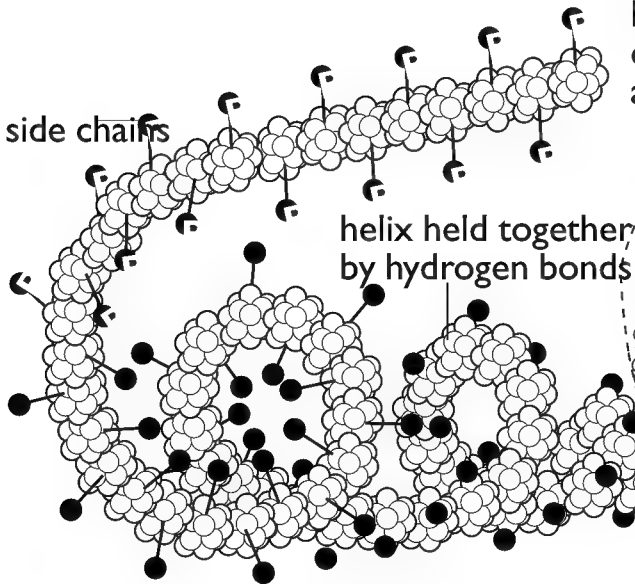
## Tertiary structure of proteins



The an alpha helix chain folds around itself forming a third level of structural organisation, just like a tangled telephone flex

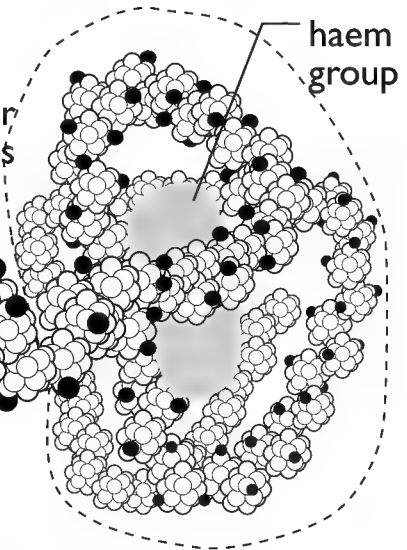
## Primary structure

Amino acids join to form a polypeptide chain



## Tertiary structure

Helix folds to form compact globular unit around Haem group



## Secondary structure

Polypeptide chain folds in upon itself to form a helix

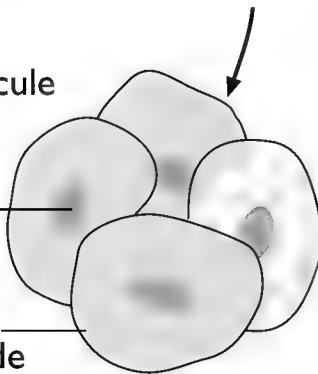
Haemoglobin molecule has four subunits

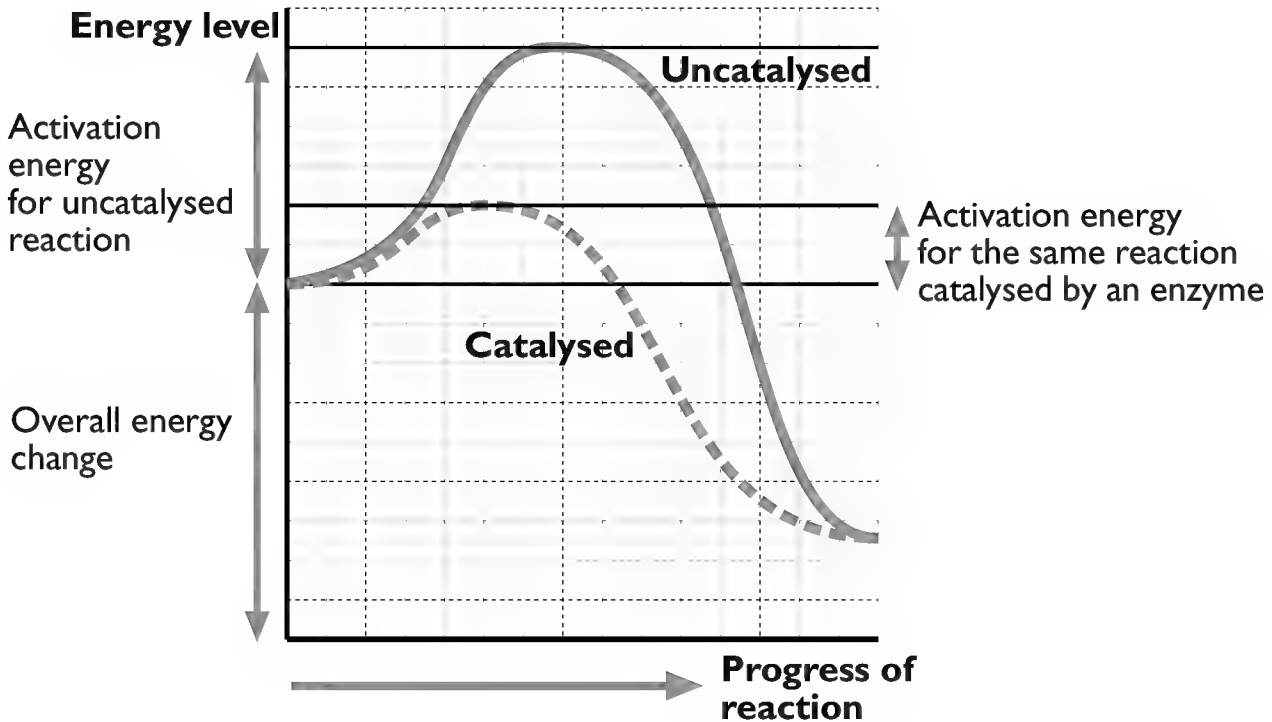
## Quaternary structure

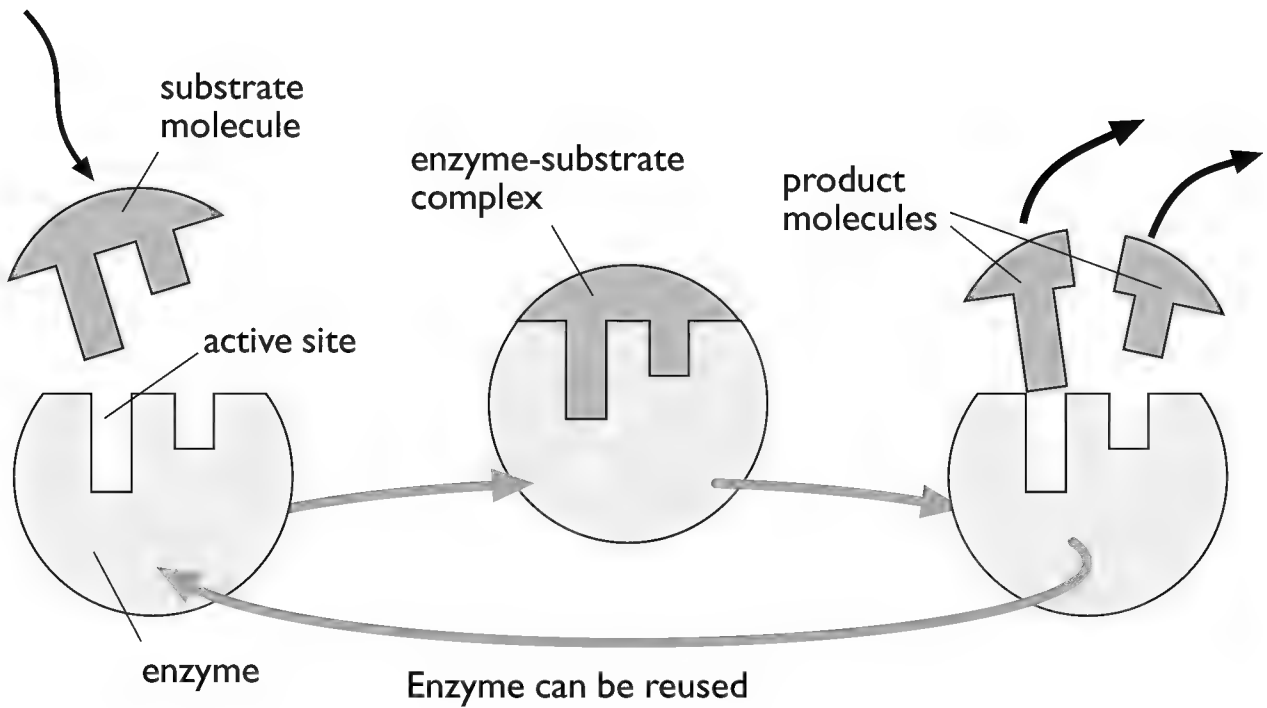
Several polypeptide chain units come together held by disulphide bridges to form a functional protein

haem group

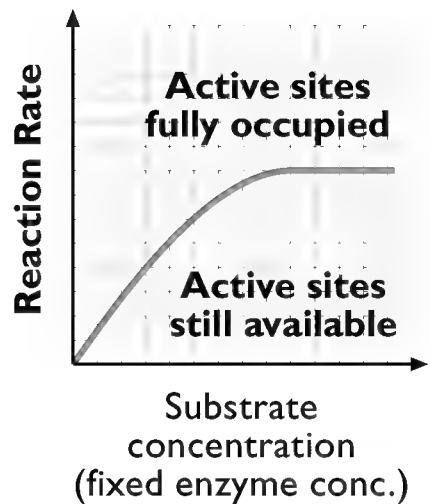
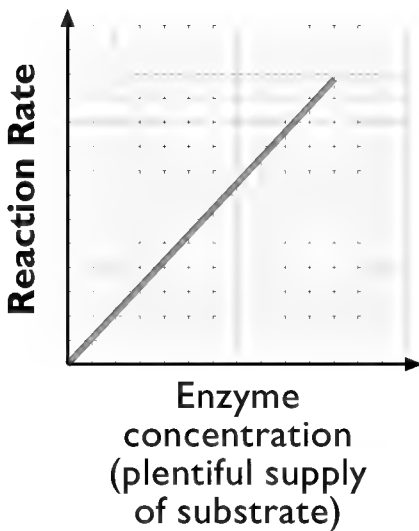
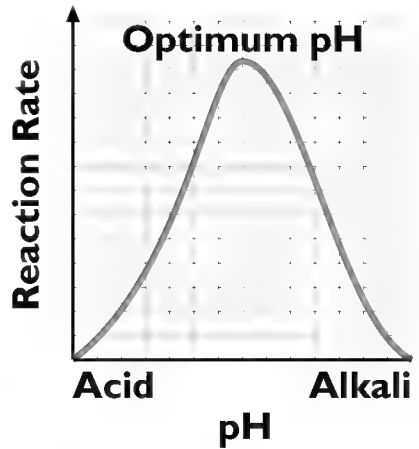
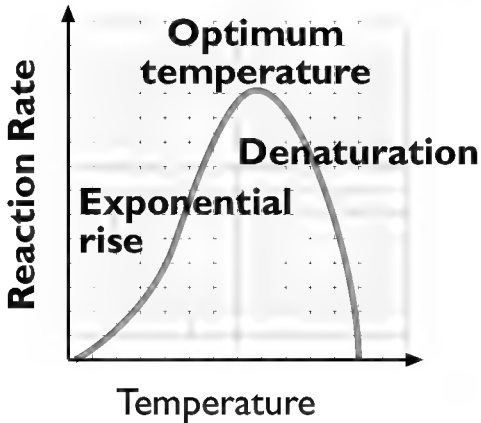
globular polypeptide subunit



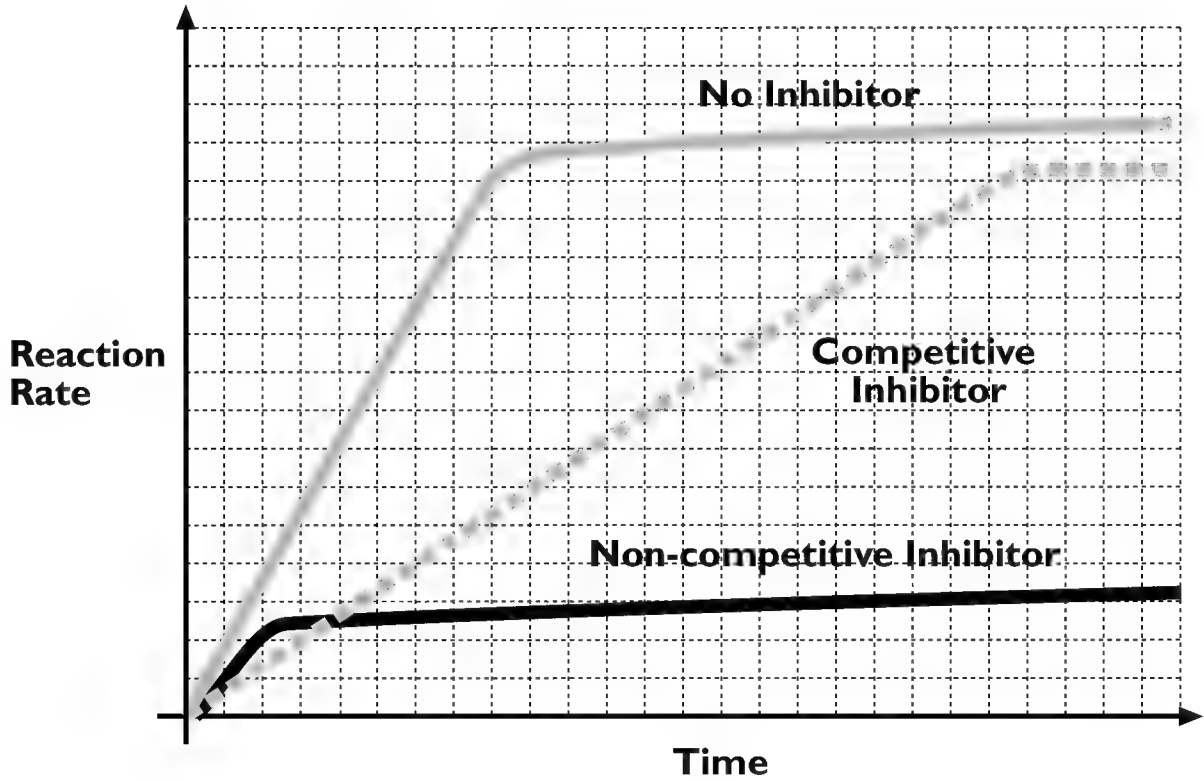


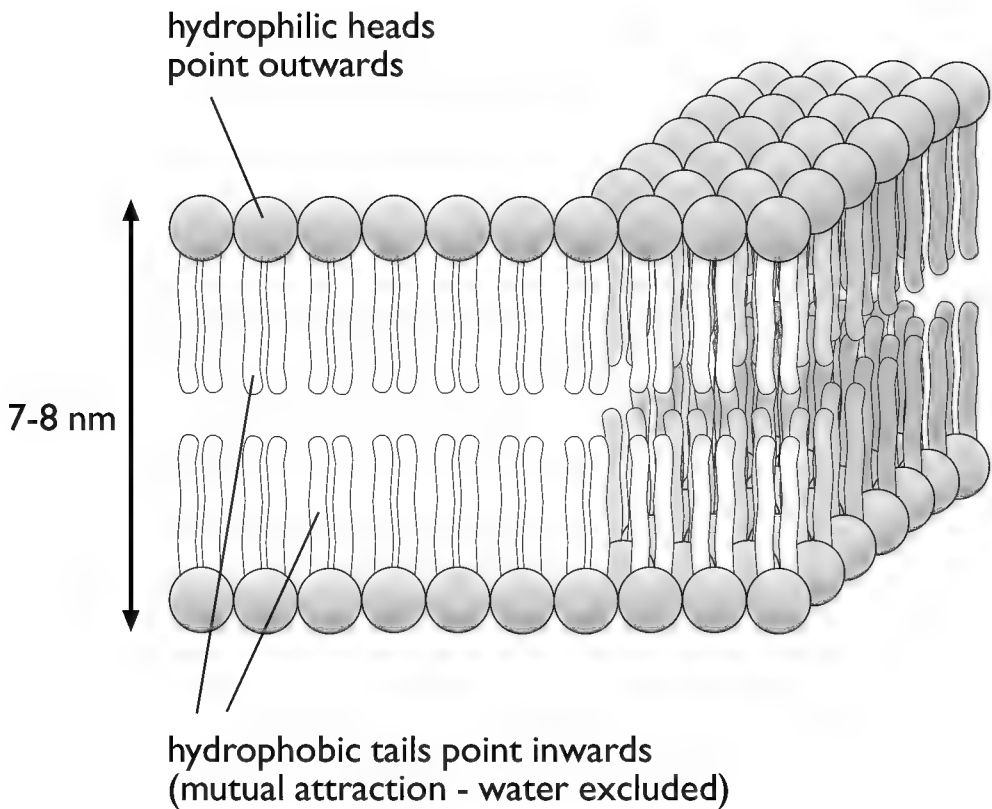


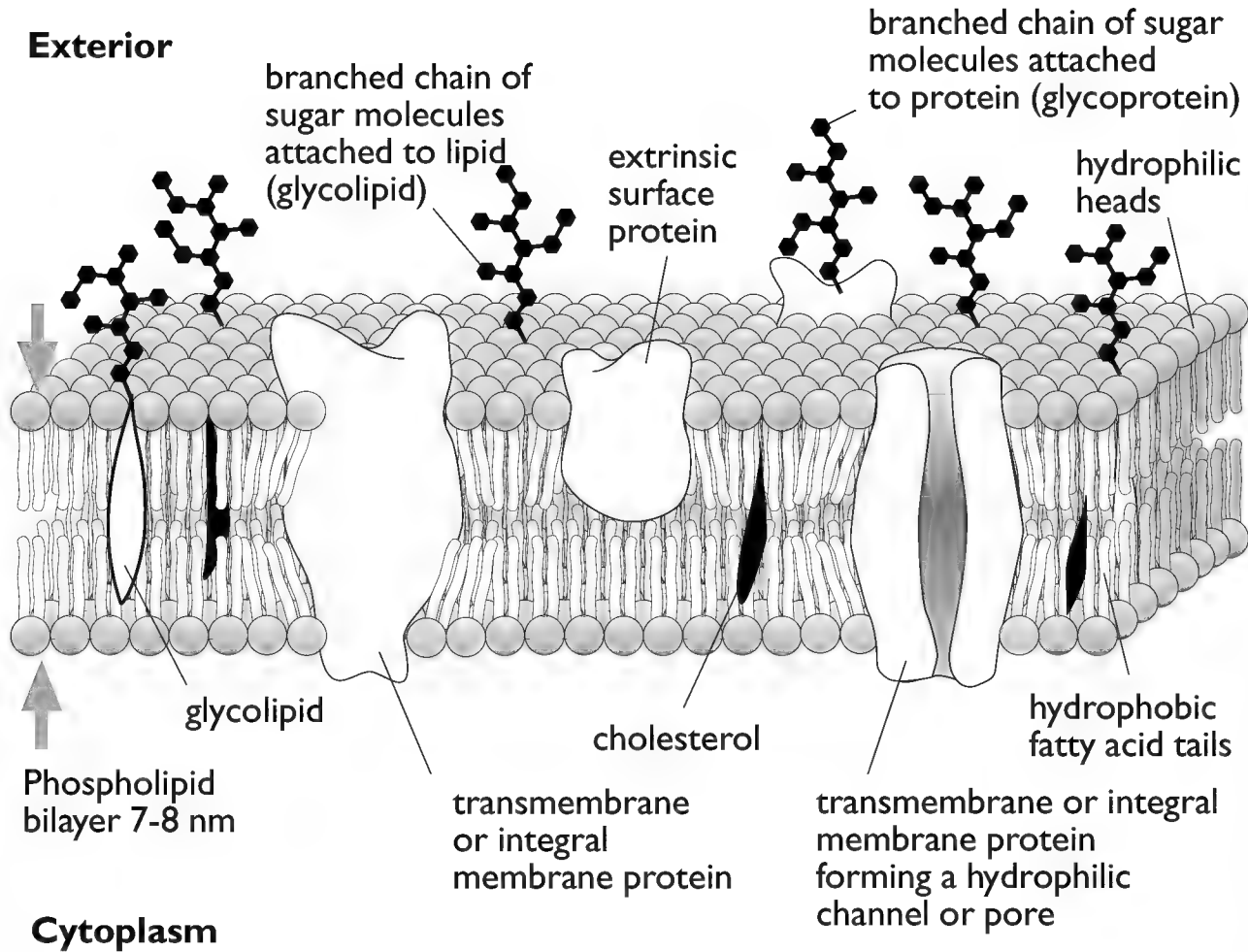
## Effects of Temperature, pH, Enzyme and Substrate Concentration on Enzyme Activity



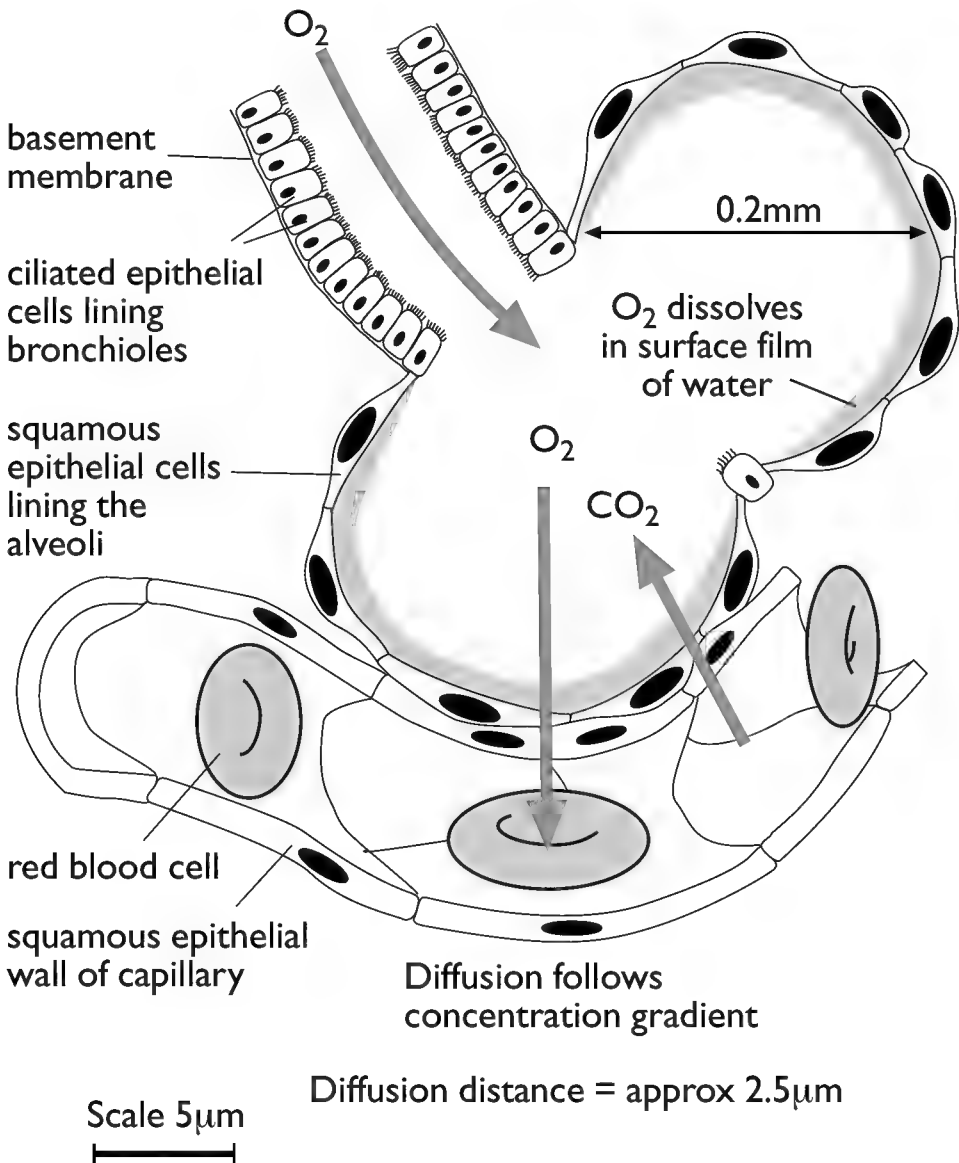




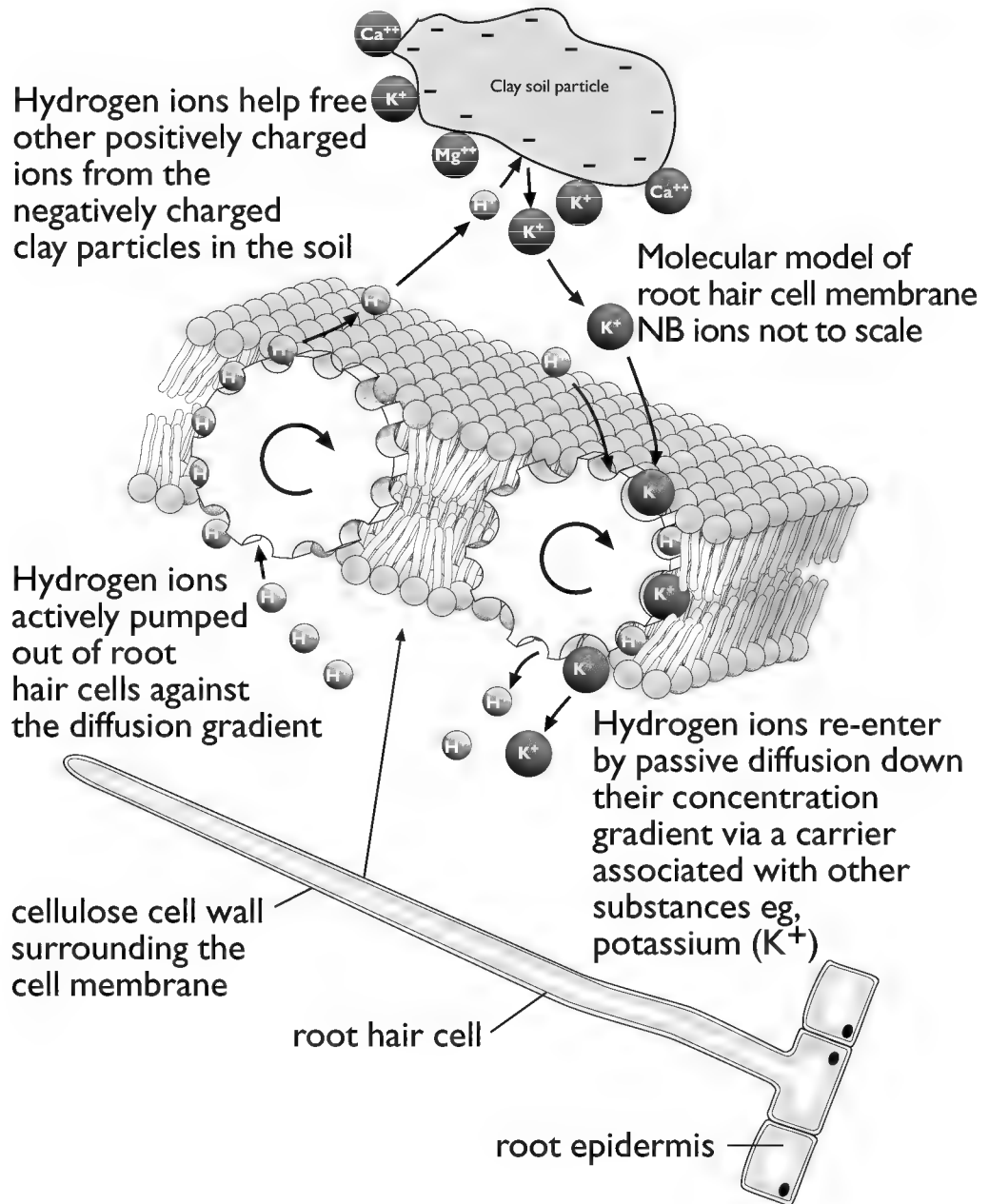




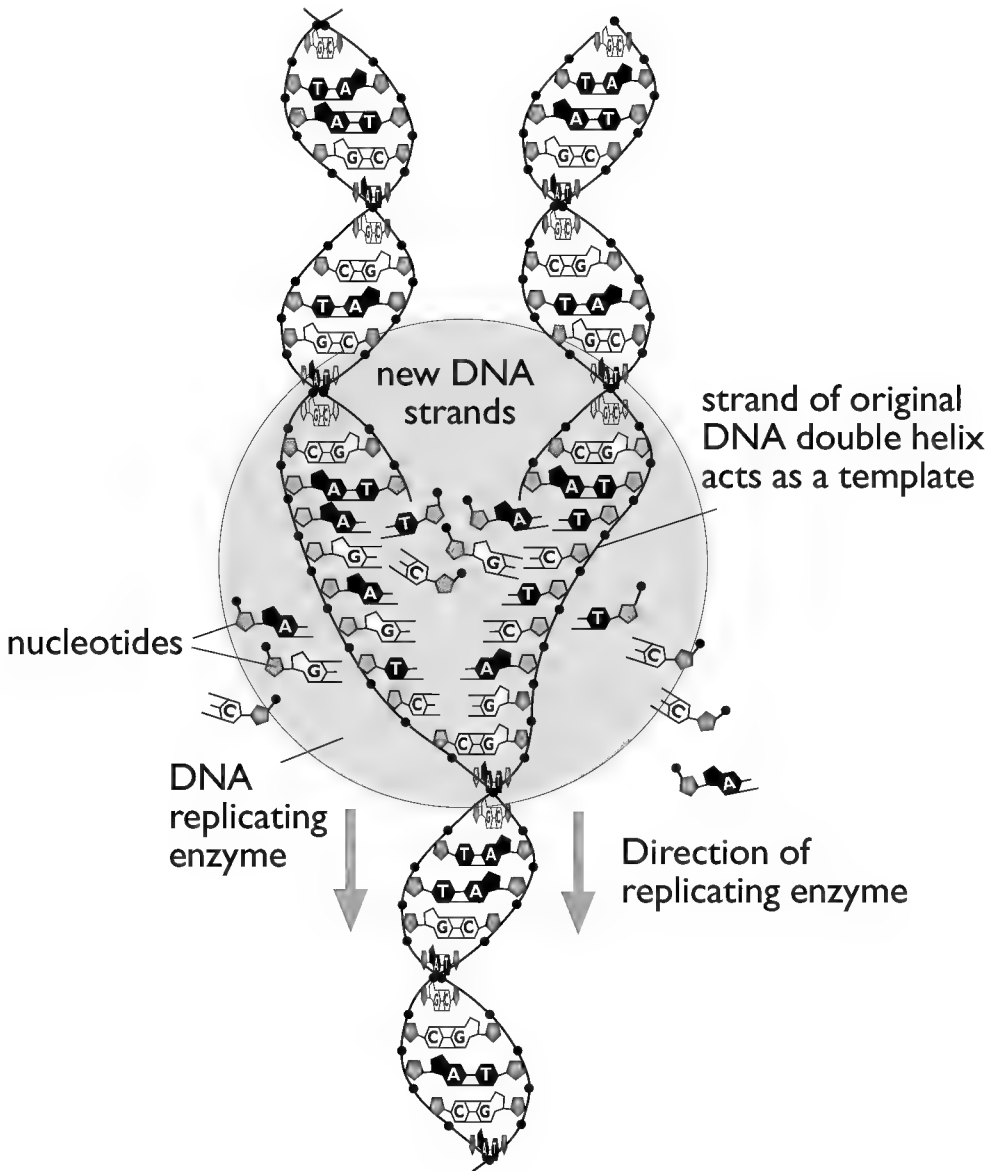
## Diffusion at alveolus



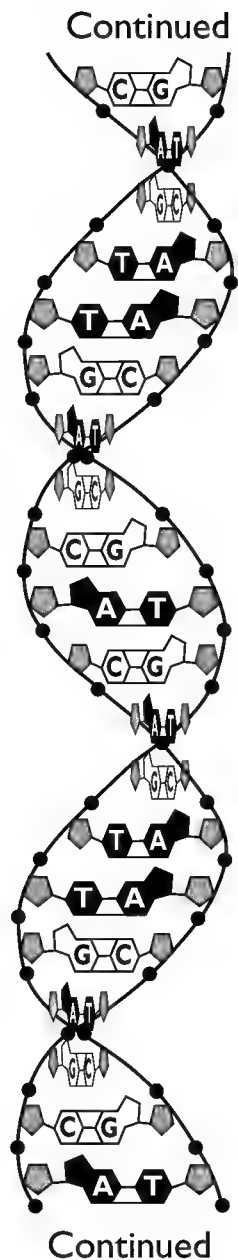
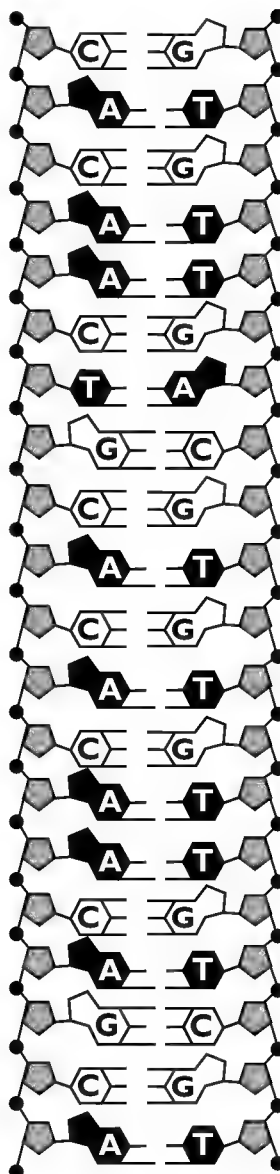
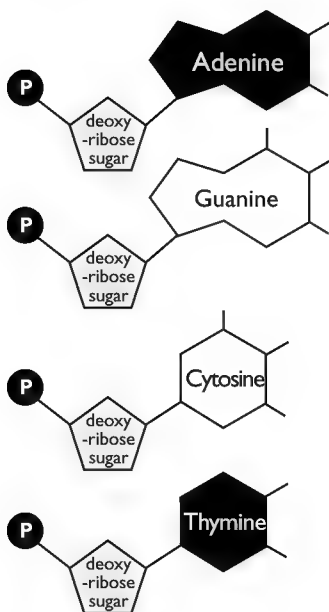
## Cation exchange by root hairs



## Structure of DNA and semi-conservative replication



## The Nucleotides of DNA



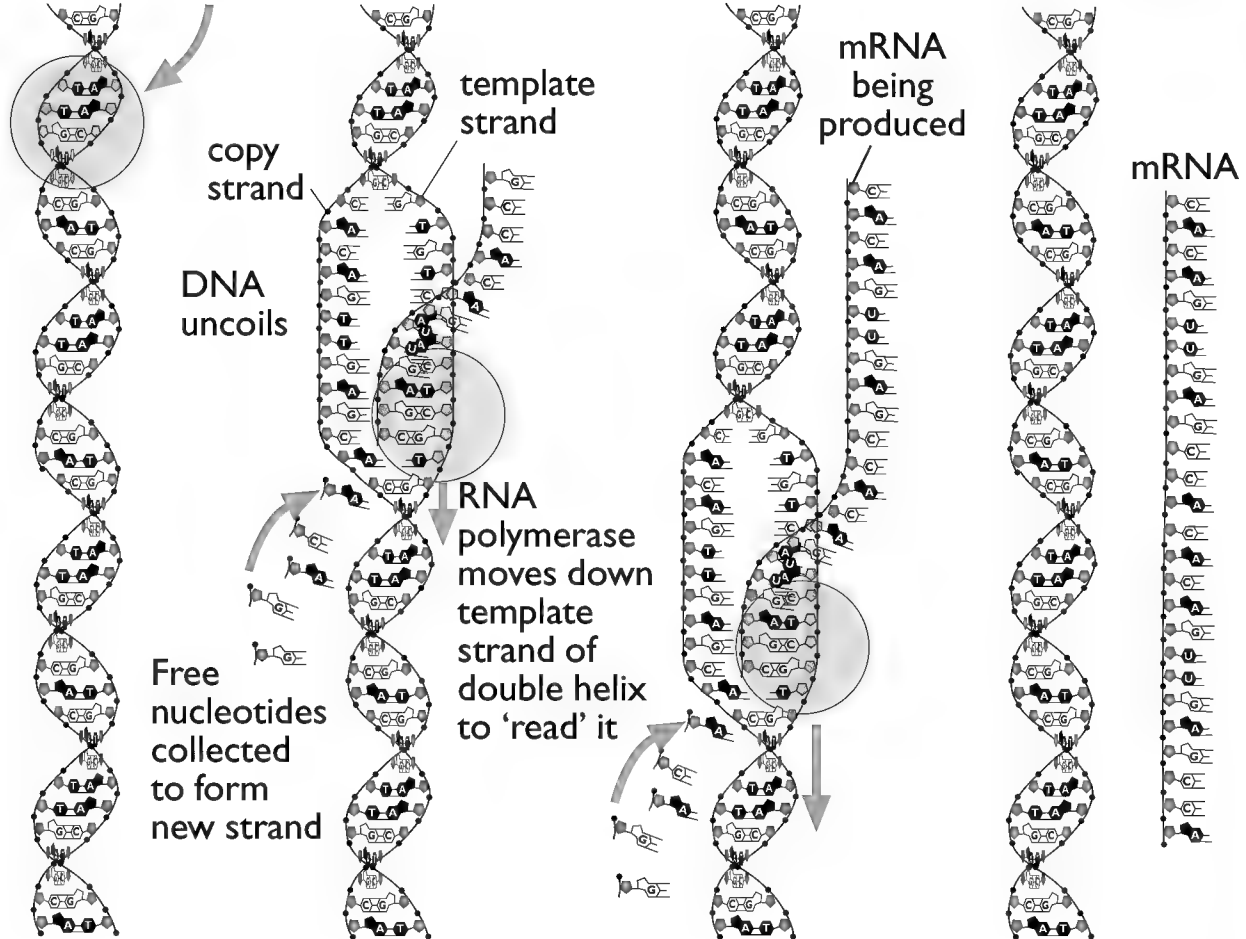
## Showing Codons for Amino Acids

| <b>Amino acid</b>  | <b>Abbr.</b> | <b>mRNA codons</b>           | <b>Essential</b> |
|--------------------|--------------|------------------------------|------------------|
| Alanine            | Ala          | GCA, GCC, GCG, GCU           |                  |
| Arginine           | Arg          | AGA, AGG, CGA, CGC, CGG, CGU | infants only     |
| Asparagine         | Asn          | AAC, AAU                     |                  |
| Aspartic acid      | Asp          | GAC, GAU                     |                  |
| Cysteine           | Cys          | UGC, UGU                     |                  |
| Glutamic acid      | Glu          | GAA, GAG                     |                  |
| Glutamine          | Gln          | CAA, CAG                     |                  |
| Glycine            | Gly          | GGA, GGC, GGG, GGU           |                  |
| Histidine          | His          | CAC, CAU                     | infants only     |
| Isoleucine         | Ile          | AUA, AUC, AUU                | E                |
| Leucine            | Leu          | CUA, CUC, CUG, CUU, UUA, UUG | E                |
| Lysine             | Lys          | AAA, AAG                     | E                |
| Methionine         | Met          | AUG (Start codon)            | E                |
| Phenylalanine      | Phe          | UUC, UUU                     | E                |
| Proline            | Pro          | CCA, CCC, CCG, CCU           |                  |
| Serine             | Ser          | AGC, AGU, UCA, UCC, UCG, UCU |                  |
| Threonine          | Thr          | ACA, ACC, ACG, ACU           | E                |
| Tryptophan         | Trp          | UGG                          | E                |
| Tyrosine           | Tyr          | UAC, UAU                     |                  |
| Valine             | Val          | GUA, GUC, GUG, GUU           | E                |
| <b>STOP CODONS</b> |              | <b>UAA, UAG, UGA</b>         |                  |

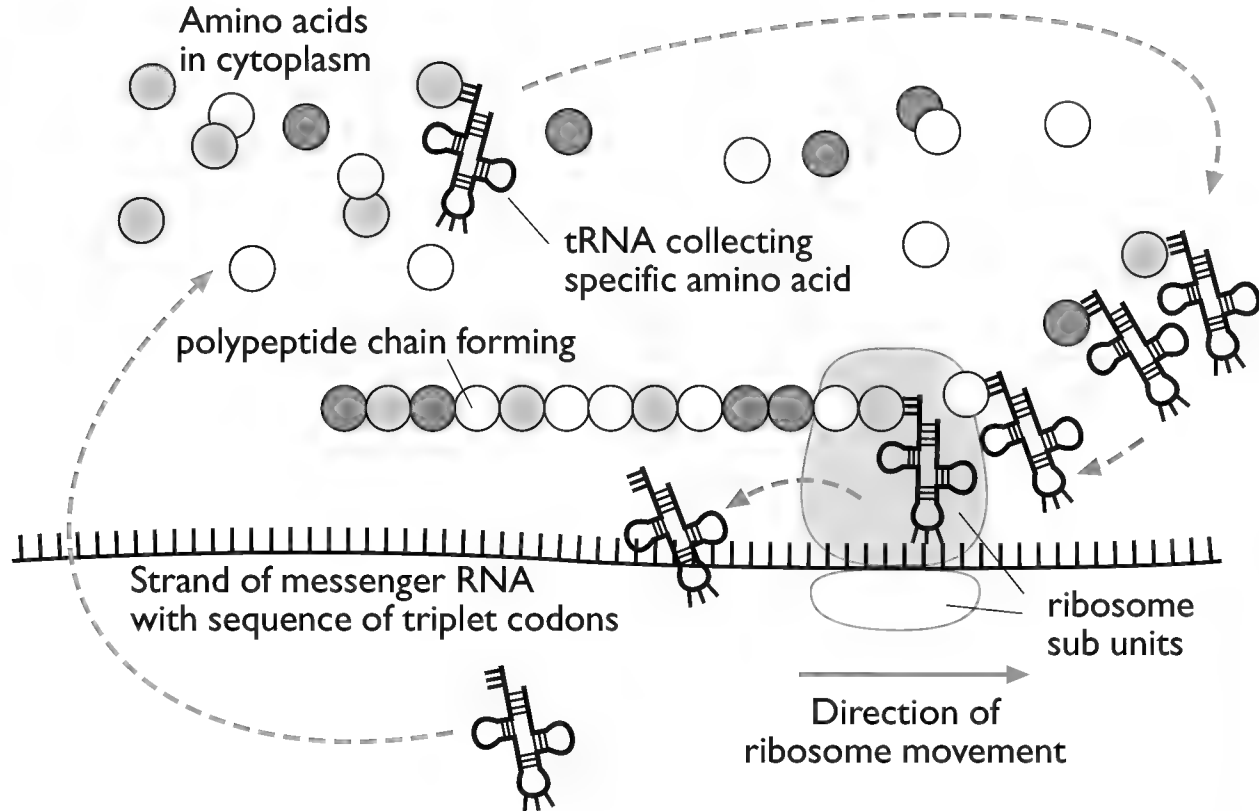


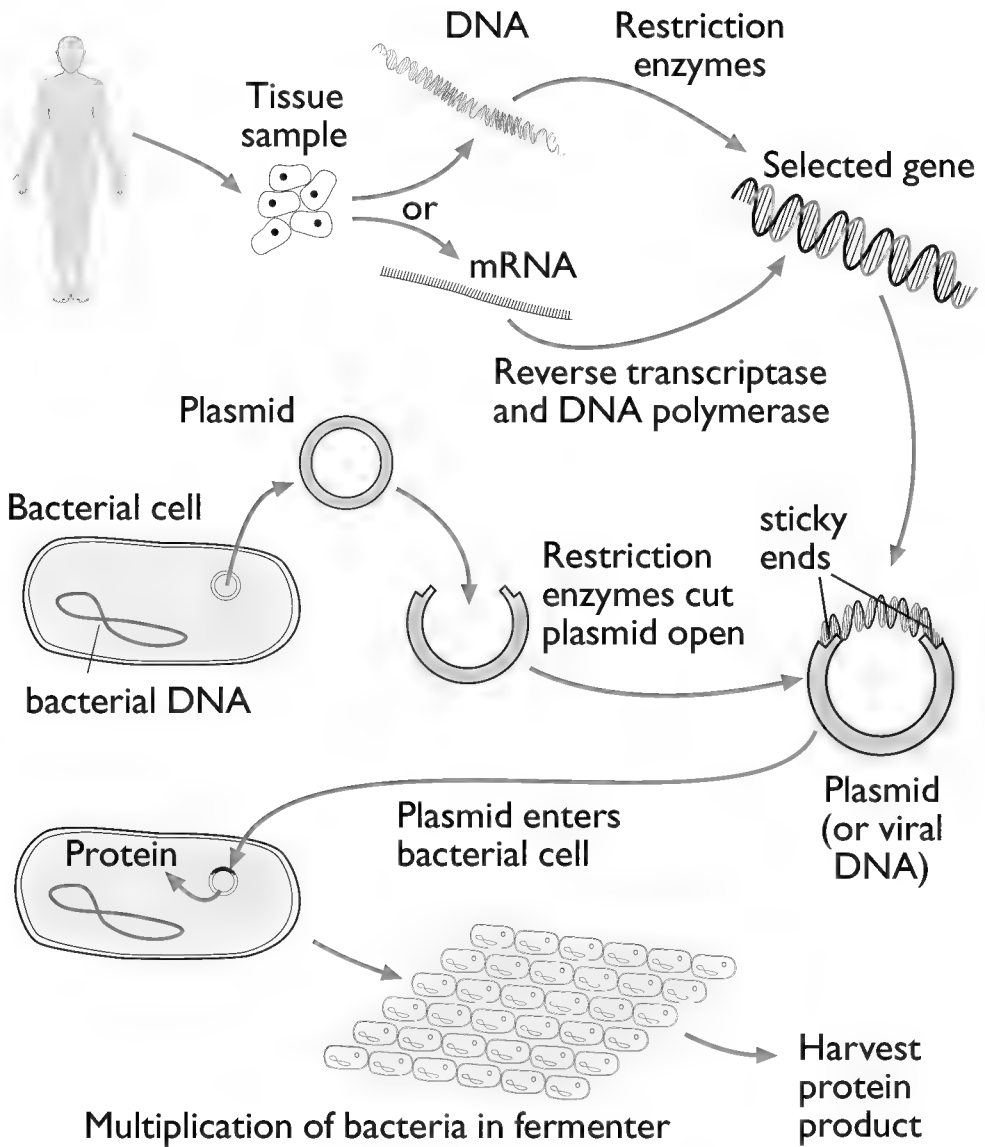
RNA polymerase attaches to DNA strand at specific codon site

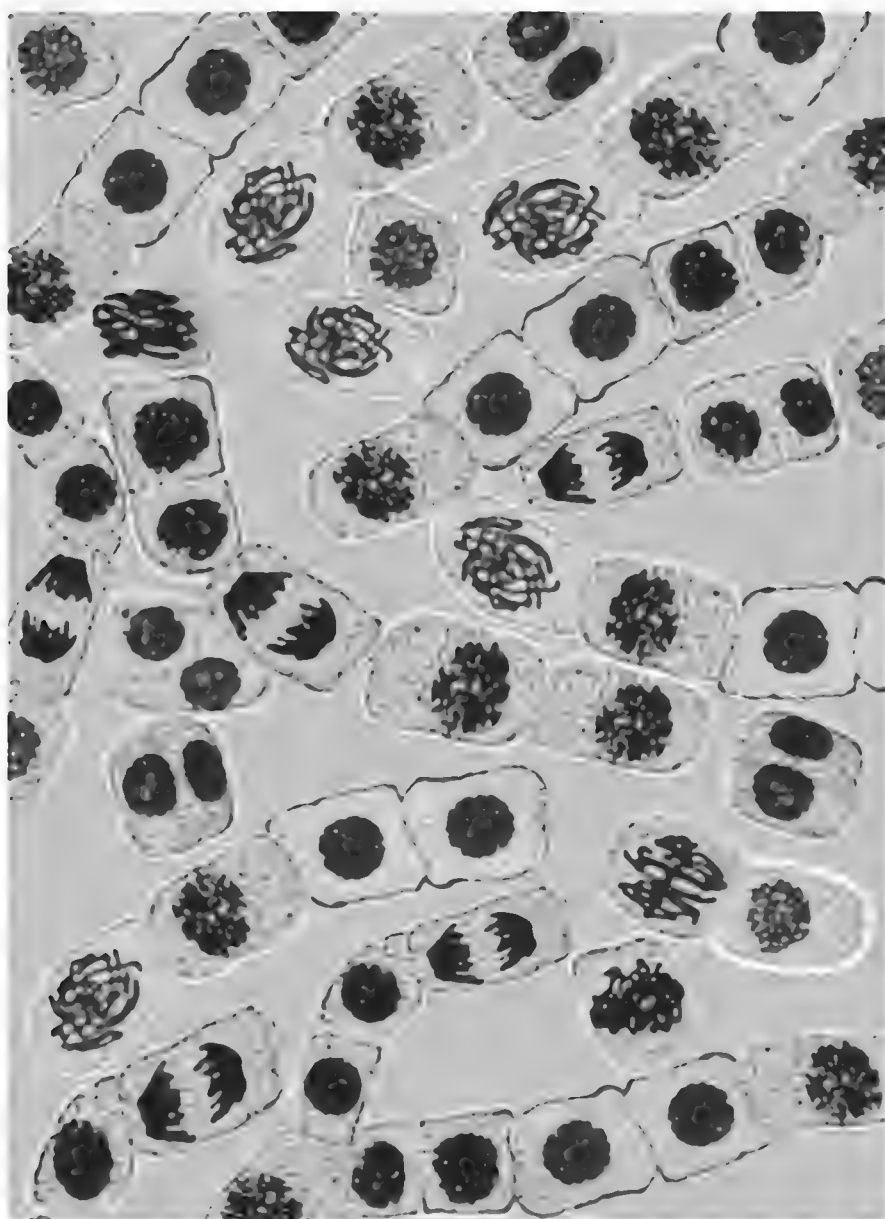
DNA double helix rewinds to original

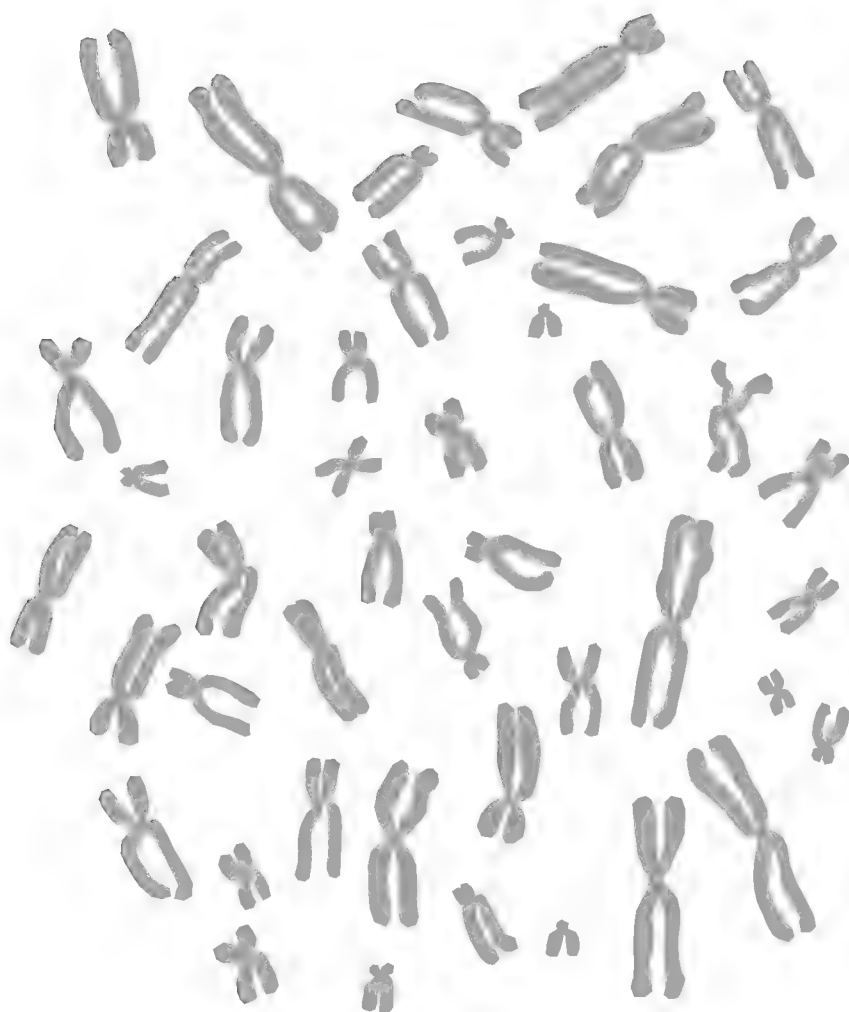


# Translation of mRNA code to build a polypeptide





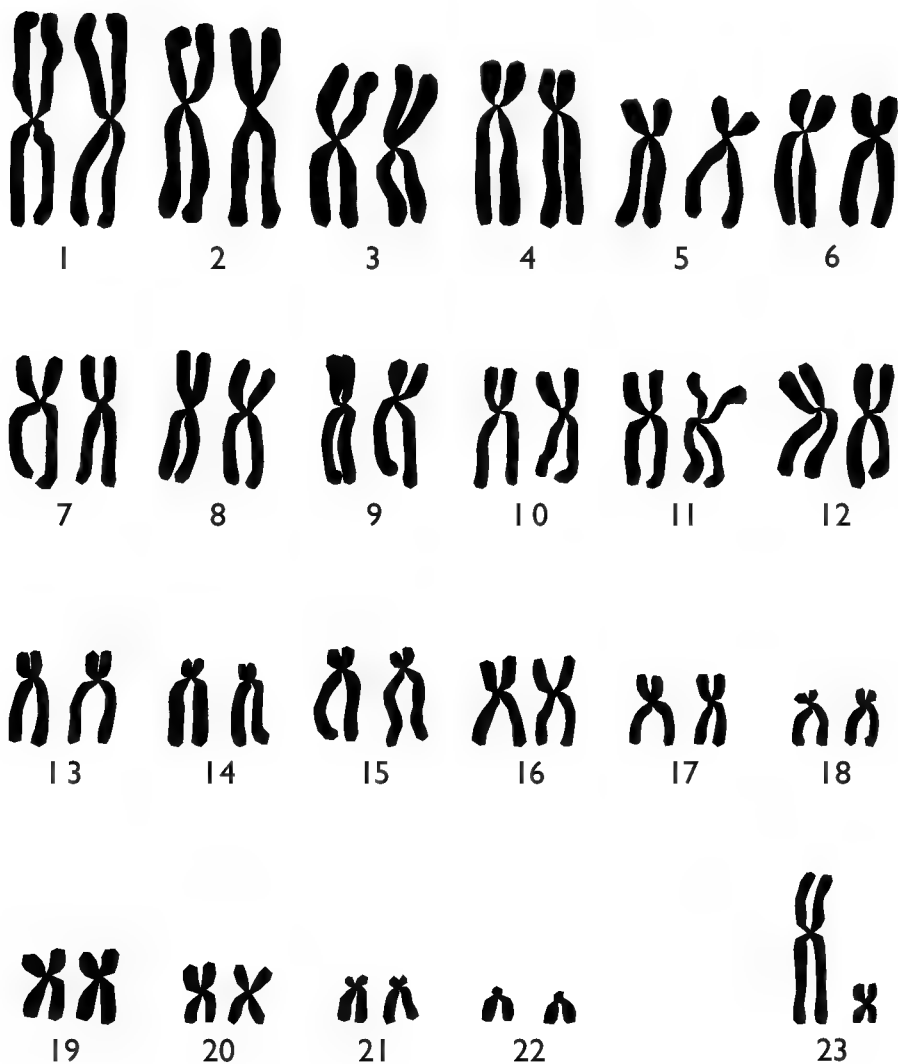


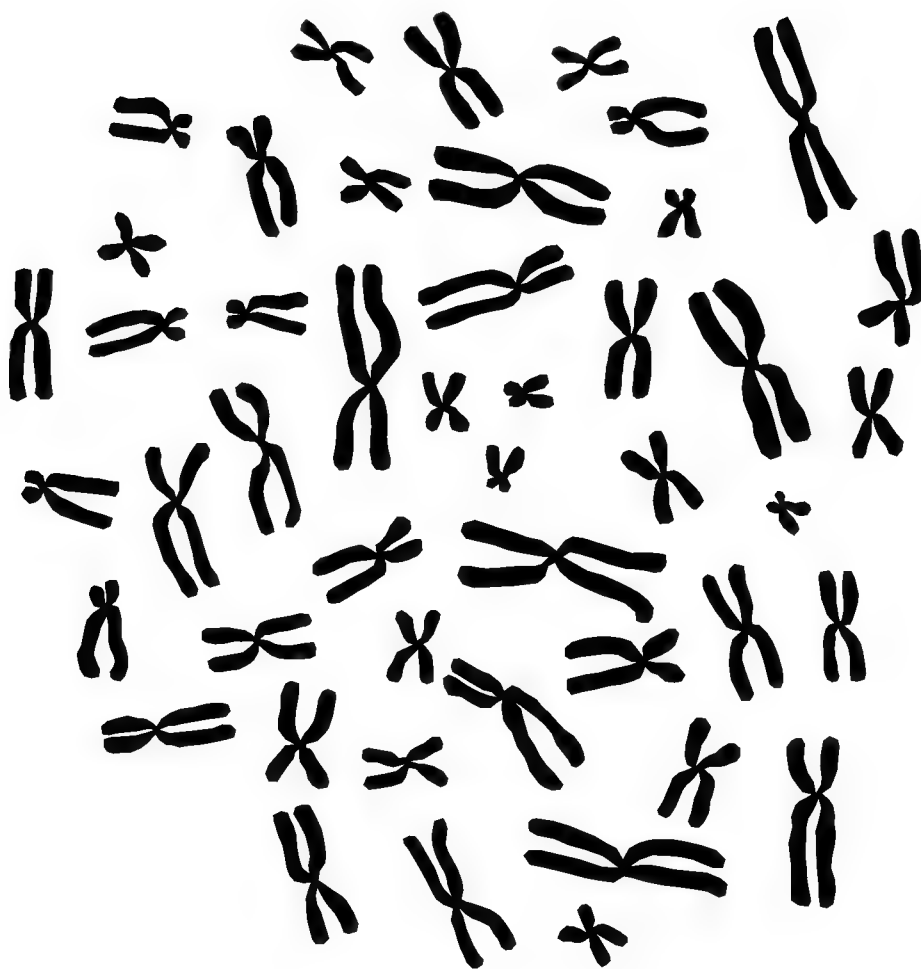


Human karyotype  
analysed into homologous pairs



**Normal Human Male**

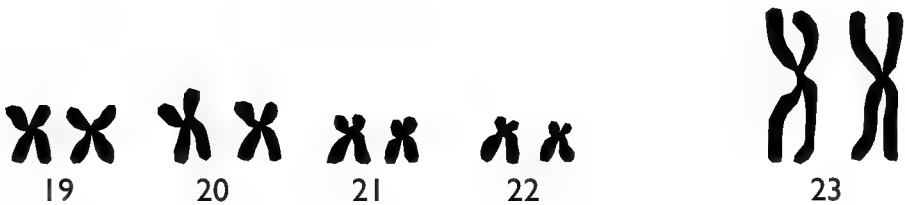
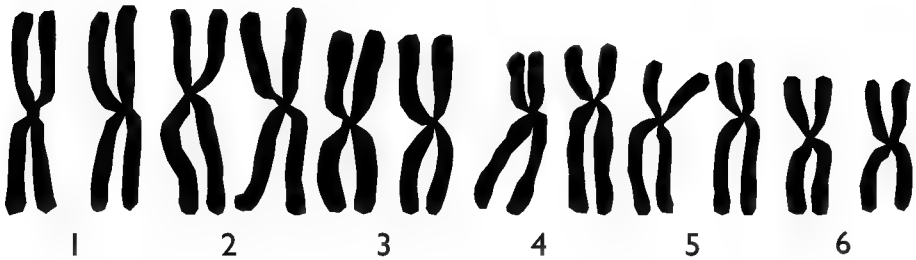




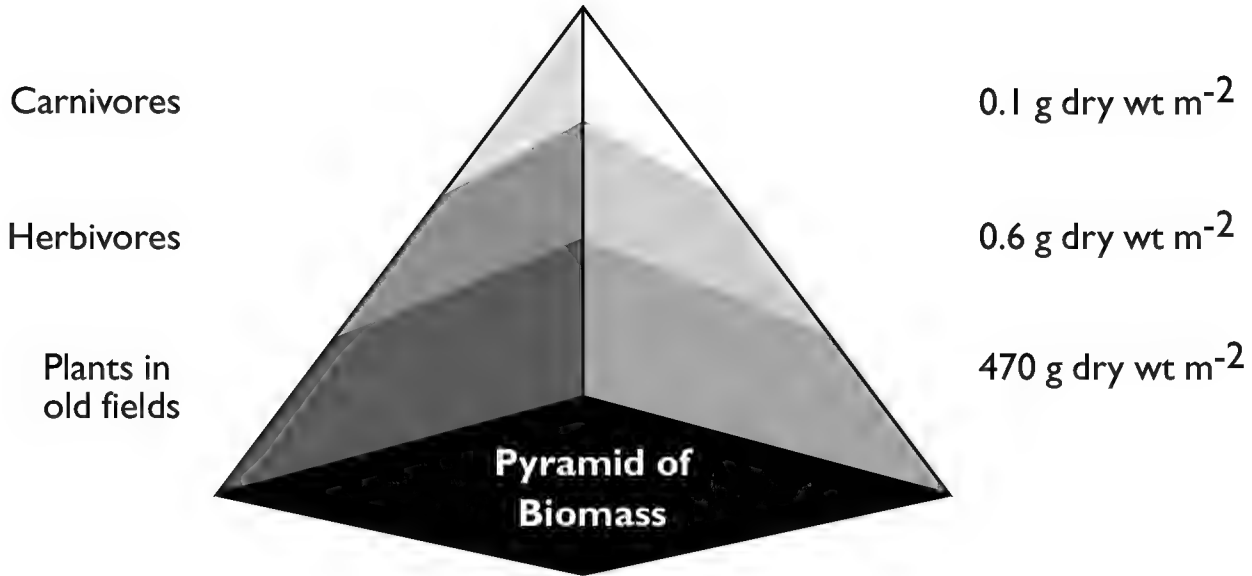
Human karyotype  
analysed into homologous pairs

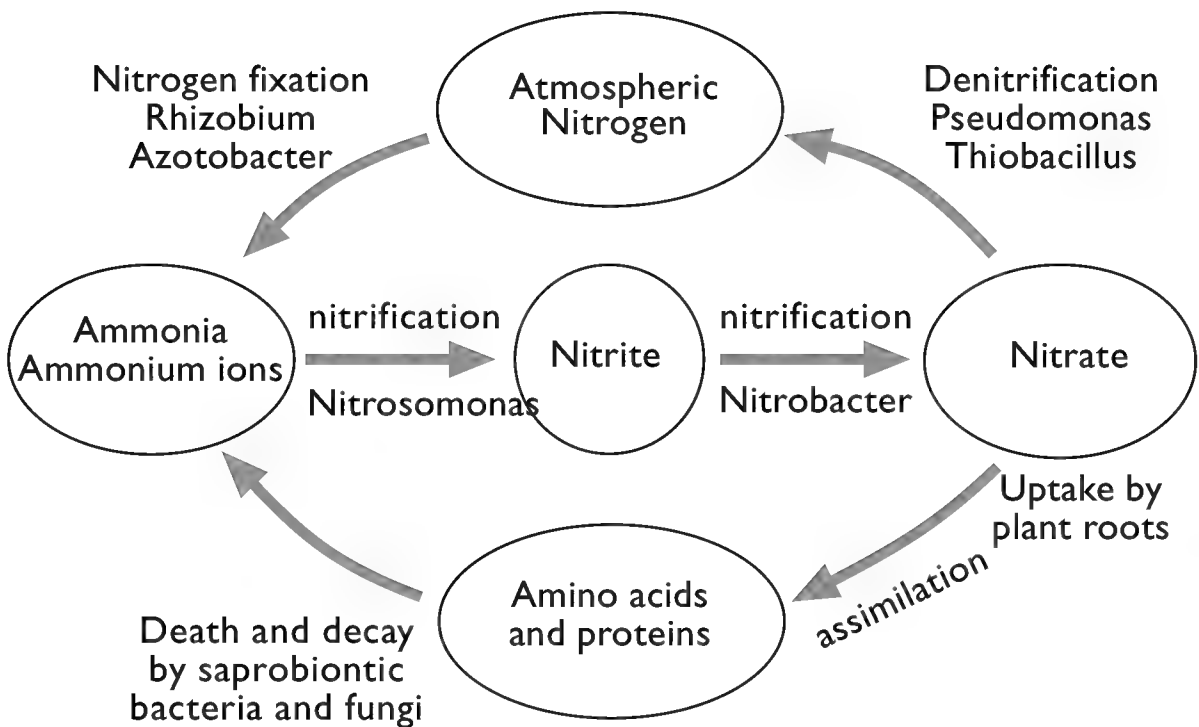


**Normal Human Female**







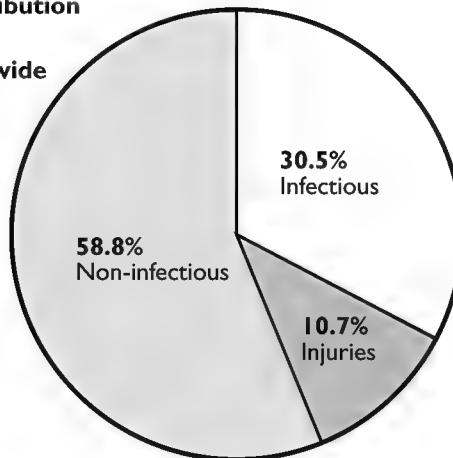


# **The World Health Organisation defines health as:**

*“a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity.”*

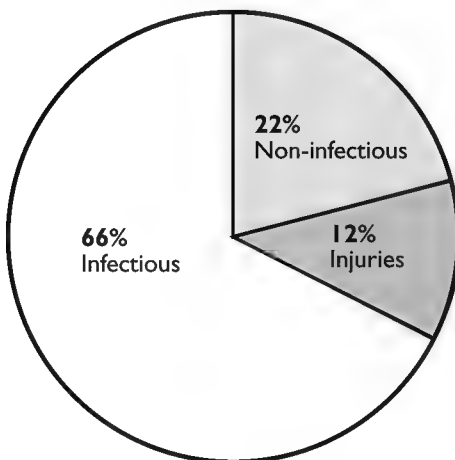
**Pattern of disease distribution**

**Worldwide**



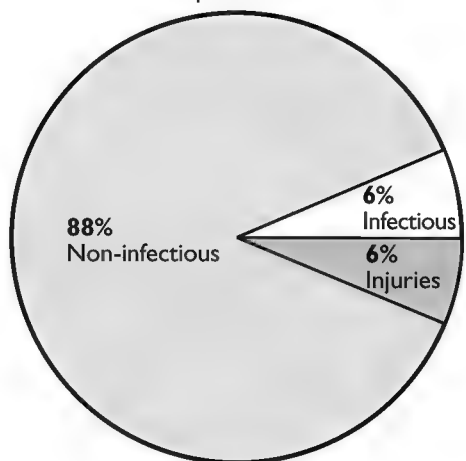
**Africa**

Including the world's poorest countries

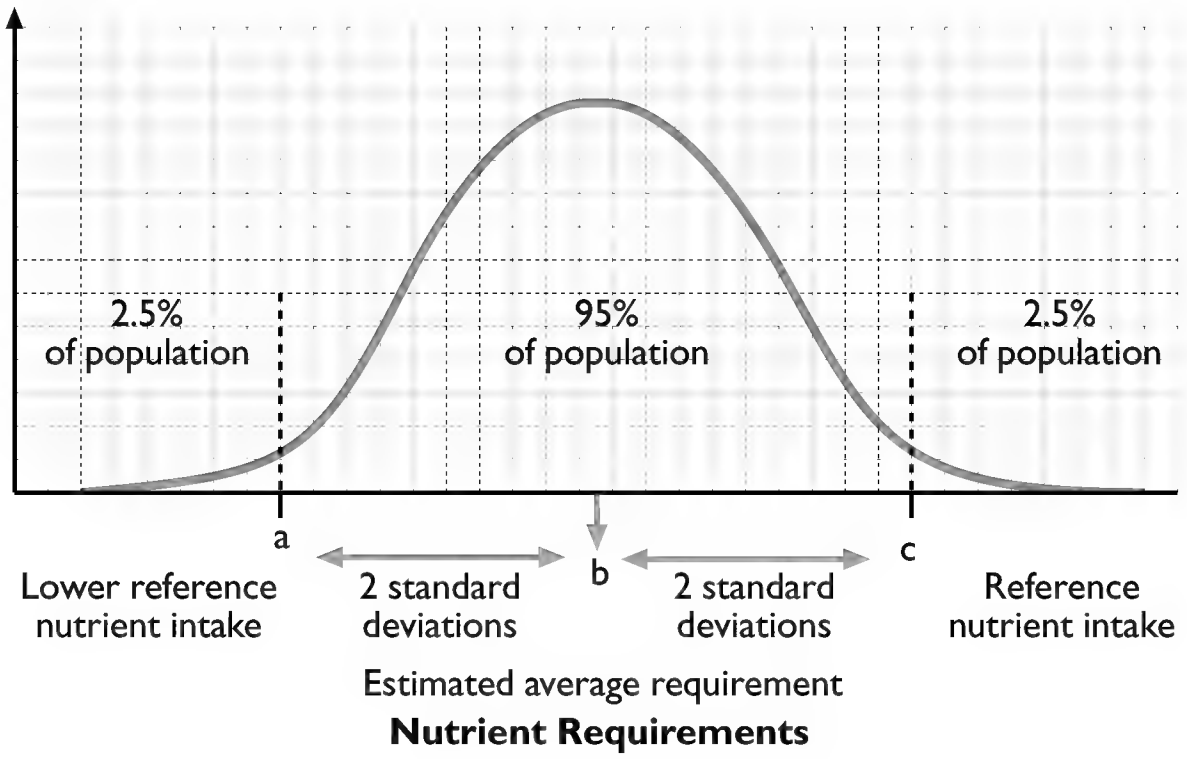


**Europe (West)**

Including some of the richest developed countries in the world

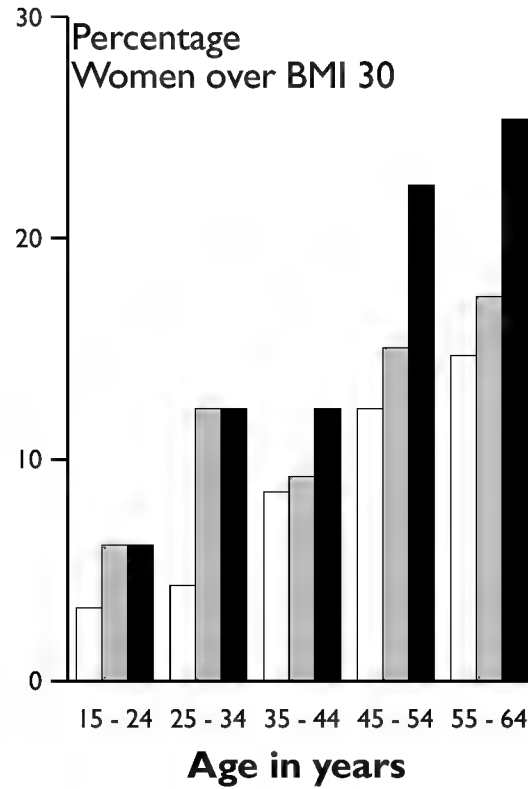
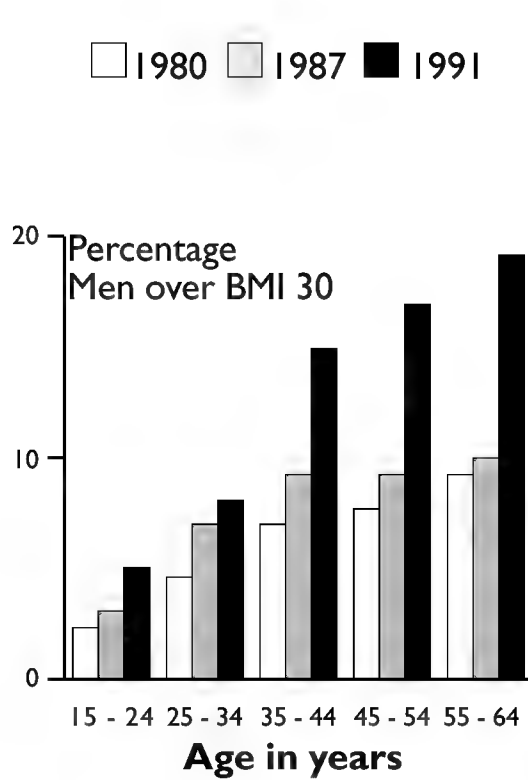


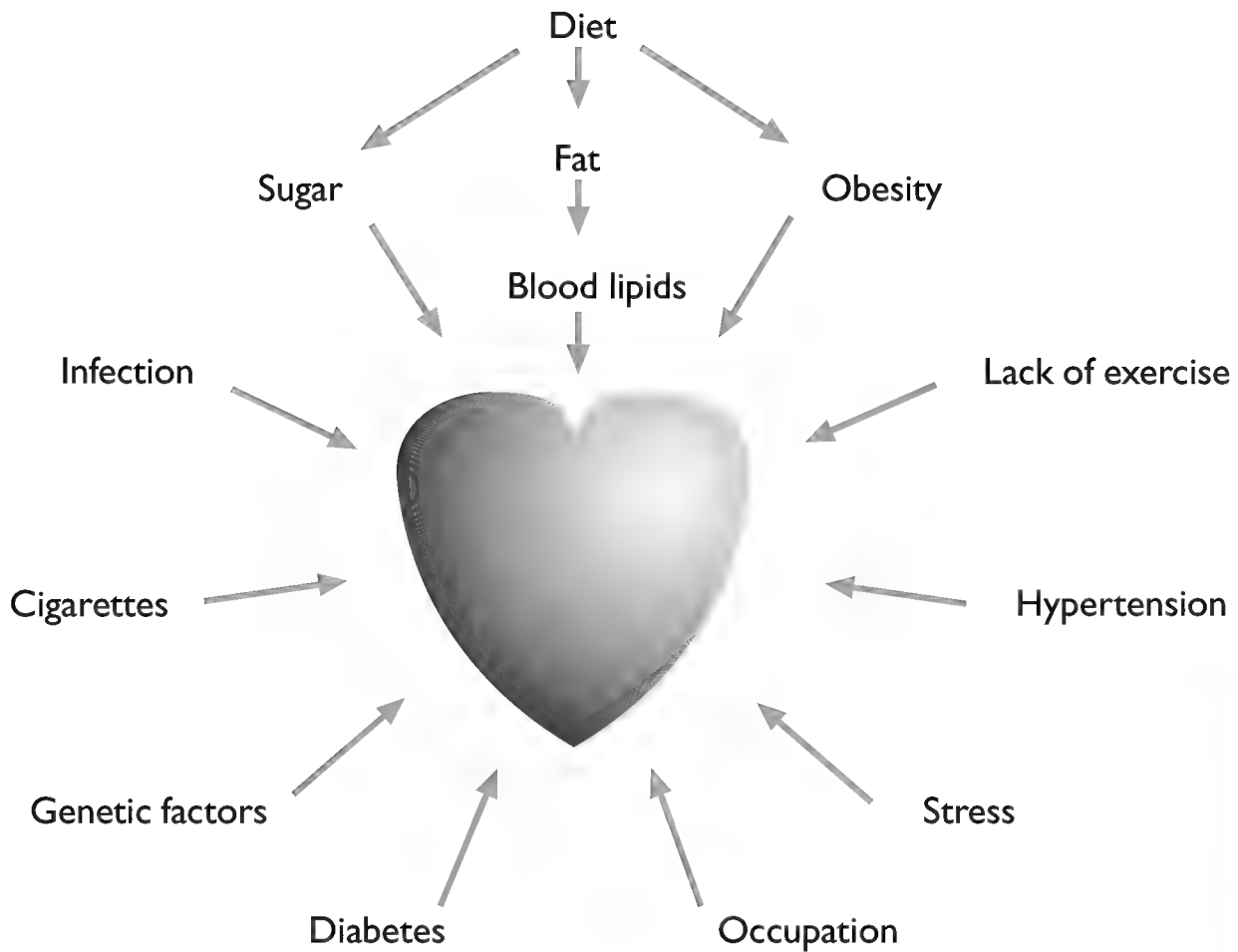
# Frequency distribution of individual nutrient requirements



| Reference Nutrient Intakes for Vitamins |           |           |           |
|-----------------------------------------|-----------|-----------|-----------|
| Age                                     | Vitamin C | Vitamin A | Vitamin D |
|                                         | mg/day    | mg/day    | mg/day    |
| 0-3 months                              | 25        | 350       | 8.5       |
| 4-6 months                              | 25        | 350       | 8.5       |
| 7-9 months                              | 25        | 350       | 7.0       |
| 10-12 months                            | 25        | 350       | 7.0       |
| 1-3 years                               | 30        | 400       | 7.0       |
| 4-6 years                               | 30        | 400       | -         |
| 7-10 years                              | 30        | 500       | -         |
| <b>Males</b>                            |           |           |           |
| 11-14 years                             | 35        | 600       | -         |
| 15-18 years                             | 40        | 700       | -         |
| 19-65 years                             | 40        | 700       | -         |
| 65+ years                               | 40        | 700       | 10.0      |
| <b>Females</b>                          |           |           |           |
| 11-14 years                             | 35        | 600       | -         |
| 15-18 years                             | 4         | 600       | -         |
| 19-65 years                             | 40        | 600       | -         |
| 65+ years                               | 40        | 700       | 10.0      |
| Pregnancy                               | +10       | +100      | 10.0      |
| <b>Lactation:</b>                       |           |           |           |
| 0-4 months                              | +30       | +350      | 10.0      |
| 4+ months                               | +30       | +350      | 10.0      |

## Increasing levels of obesity







# Coronary heart disease risk factors questions

| Age       | Sex                  | Weight                    | % Animal Fat in Diet |         |
|-----------|----------------------|---------------------------|----------------------|---------|
| 10-20     | Female under 40      | More than 2kg below ideal | No animal fat        |         |
| 21-30     | Female under 40-50   | Within 2kg of ideal       | 10% animal fat       |         |
| 31-40     | Female under over 50 | 15kg over ideal           | 20% animal fat       |         |
| 41-50     | Male                 | 20kg over ideal           | 30% animal fat       |         |
| 51-60     | Stocky male          | 25kg over ideal           | 40% animal fat       |         |
| 61 & over | Bald stocky male     | 30kg over ideal           | 50% animal fat       | Total 1 |

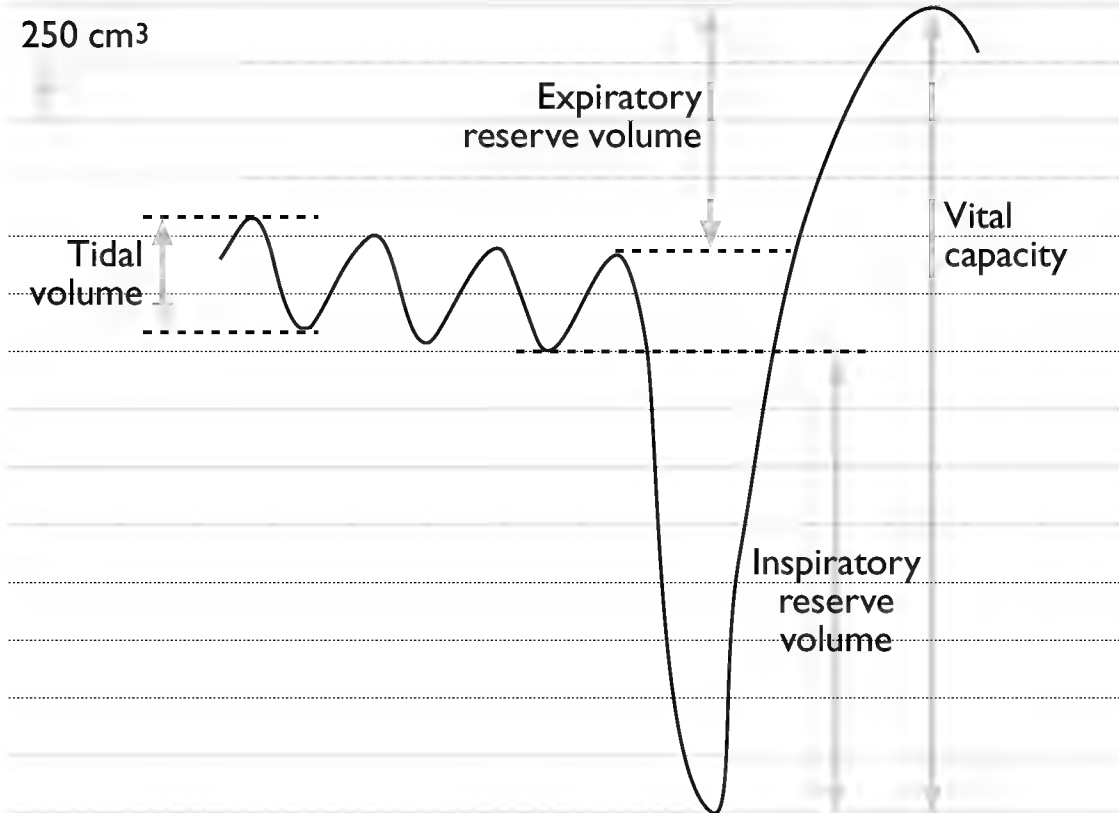
+                      +                      +                      =

| Exercise                     | Tobacco smoking       | History of heart disease | Blood pressure            |         |
|------------------------------|-----------------------|--------------------------|---------------------------|---------|
| Hard manual job & exercise   | Non smoker            | None                     | Upper reading 100         |         |
| Manual job & medium exercise | Cigar or pipe smoker  | 1 relative over 60       | Upper reading 120         |         |
| Office job & hard exercise   | 10 cigs. aday or less | 2 relatives over 60      | Upper reading 140         |         |
| Office job & medium exercise | 20 cigarettes aday    | 1 relative under 60      | Upper reading 160         |         |
| Office job & light exercise  | 30 cigarettes aday    | 2 relatives under 60     | Upper reading 180         |         |
| No exercise                  | 40 cigarettes aday    | 3 relatives under 60     | Upper reading 200 or more | Total 2 |

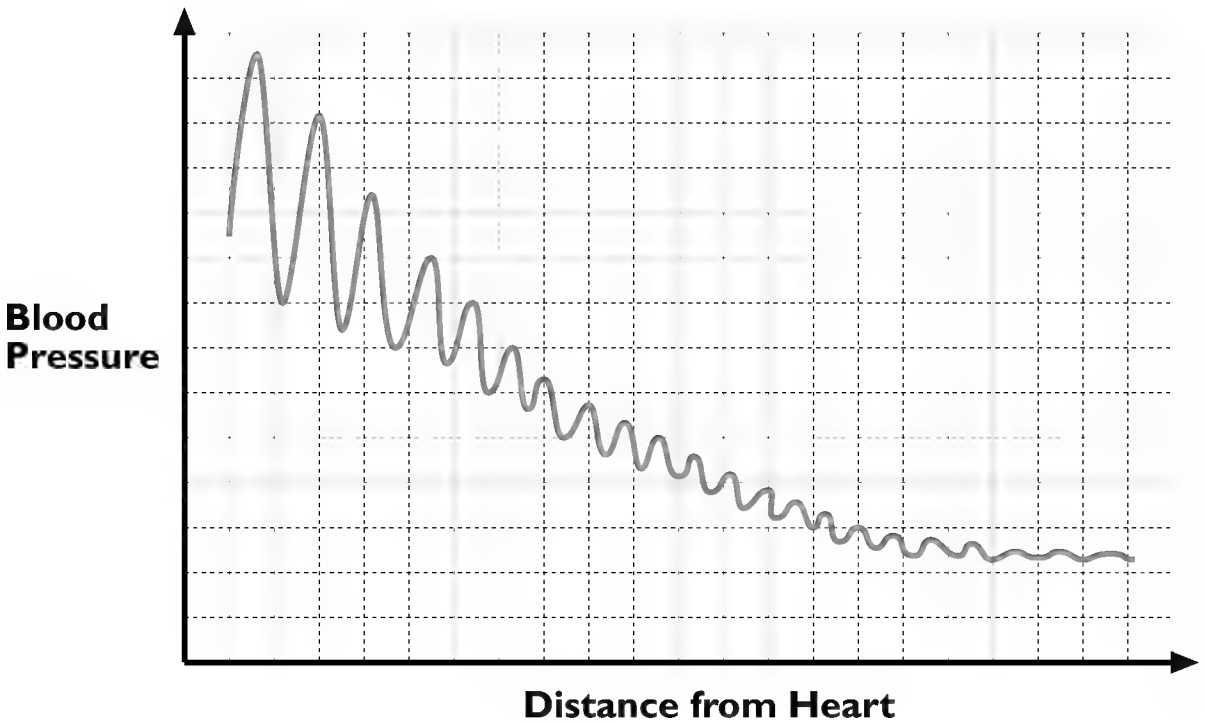
+                      +                      +                      =

The higher the total the higher the risk of CHD

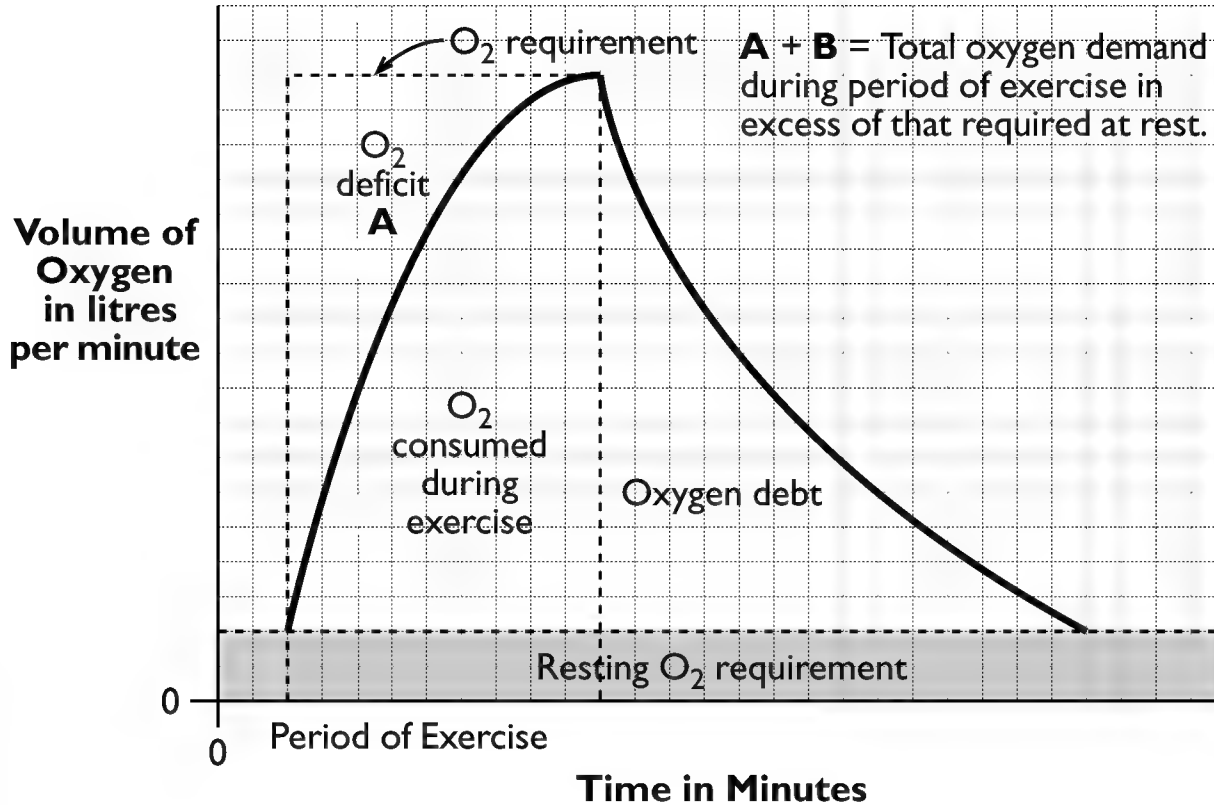
Grand Total = \_\_\_\_\_

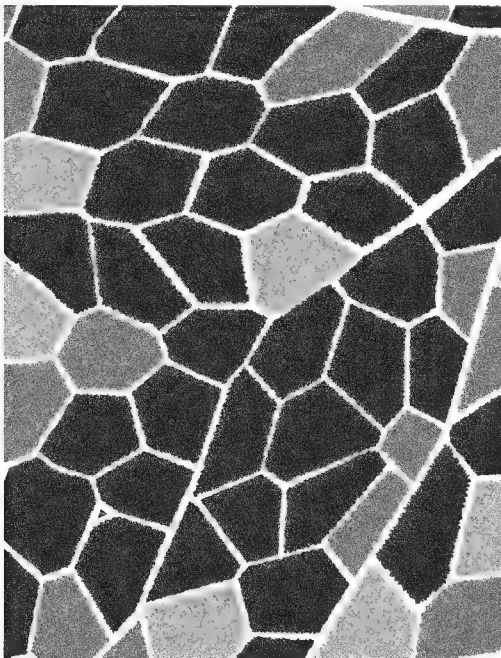


This trace does not show the total lung volume and residual volume, which are not easily measured. With increasing age the residual volume increases from about 20% of the total lung volume to more than 30%.

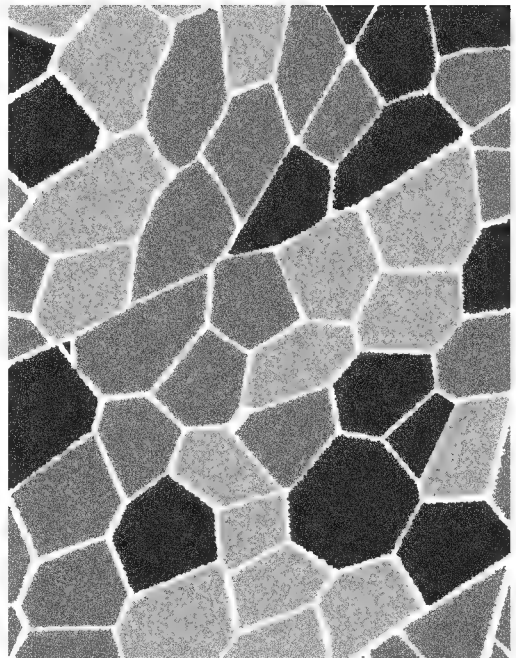


## Oxygen deficit and oxygen debt





**Sprint Runner**  
**70% Fast-twitch fibres** (*light*)

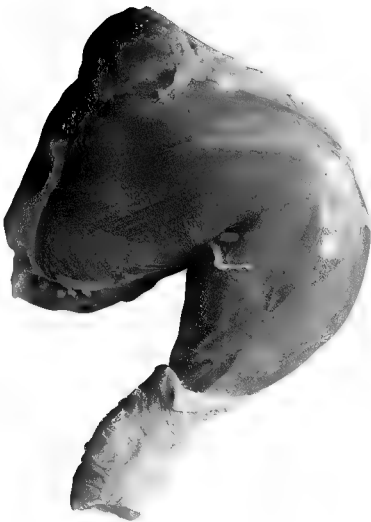
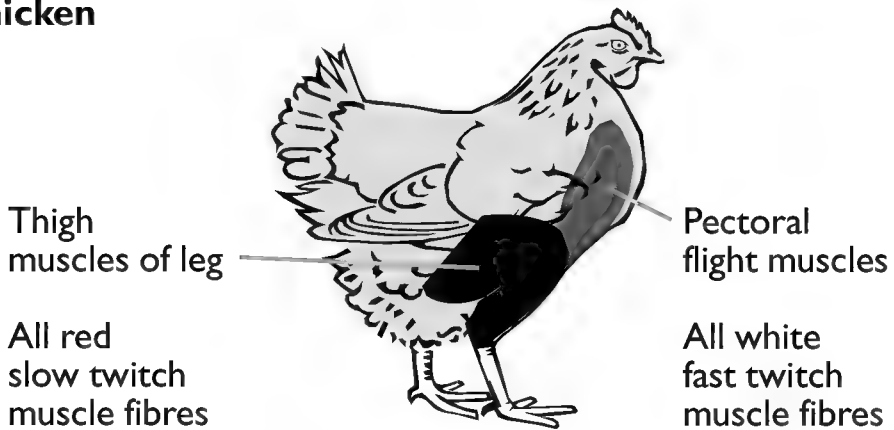


**Marathon Runner**  
**90% Slow twitch fibres** (*dark*)

## Skeletal Muscle Fibre Types and their Properties

| Type | Colour | Contraction | Metabolism                                  | Properties                                 |
|------|--------|-------------|---------------------------------------------|--------------------------------------------|
| I    | Red    | Slow-twitch | Oxidative<br>(aerobic)                      | Fatigue<br>resistant<br>Low force/power    |
| IIA  | White  | Fast-twitch | Oxidative/glycolytic<br>(aerobic/anaerobic) | Intermediate                               |
| IIB  | White  | Fast-twitch | Glycolytic<br>(anaerobic)                   | Fatigue<br>susceptible<br>High force/power |

## Chicken

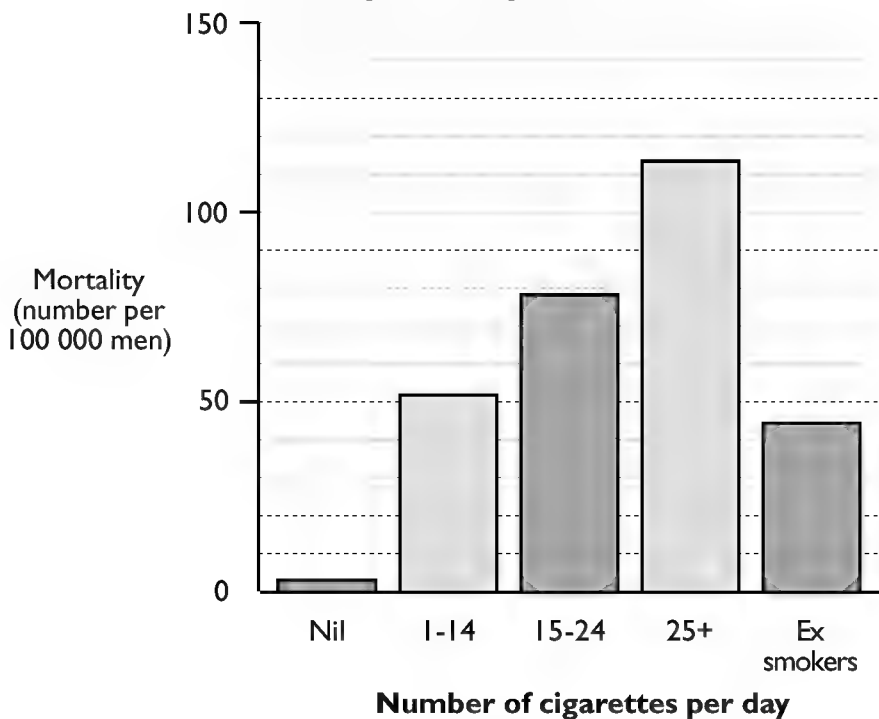


**Dark red chicken leg**

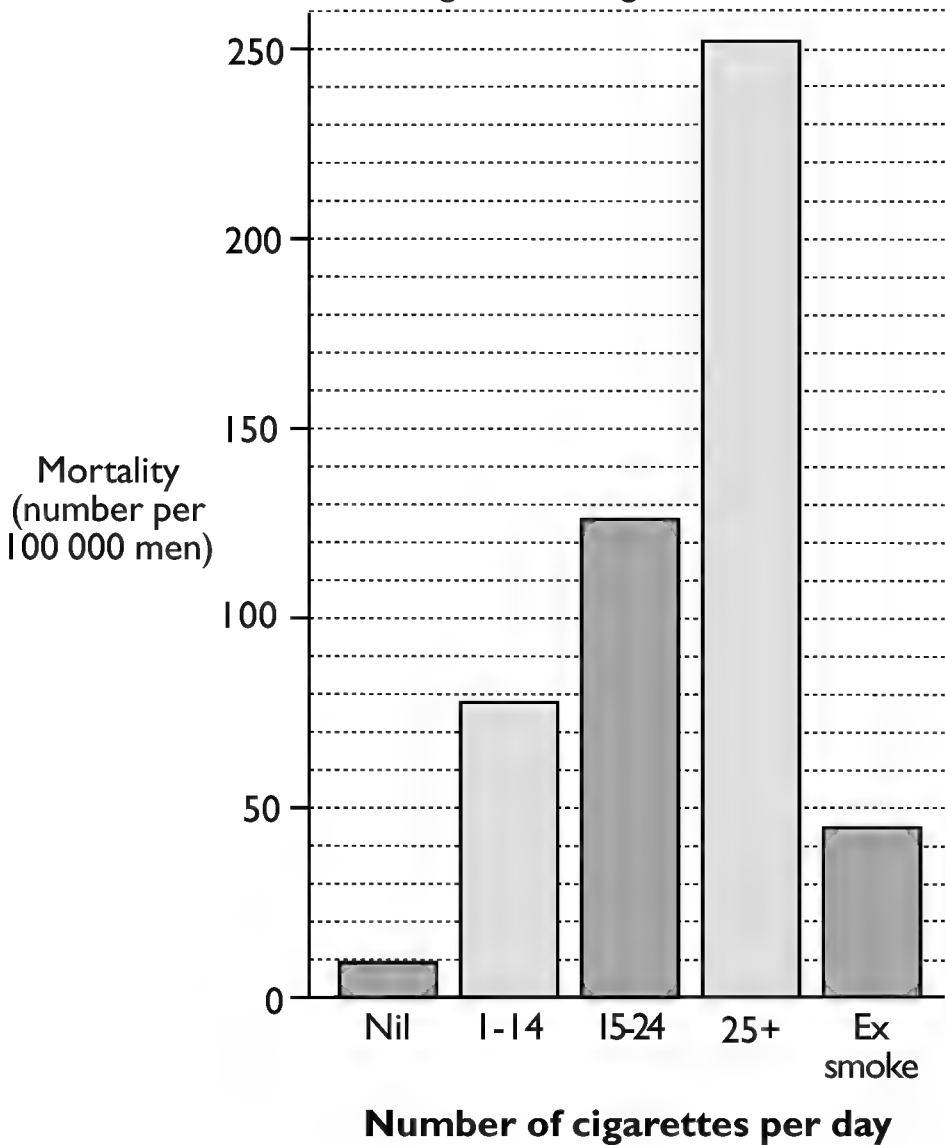


**White chicken breast**

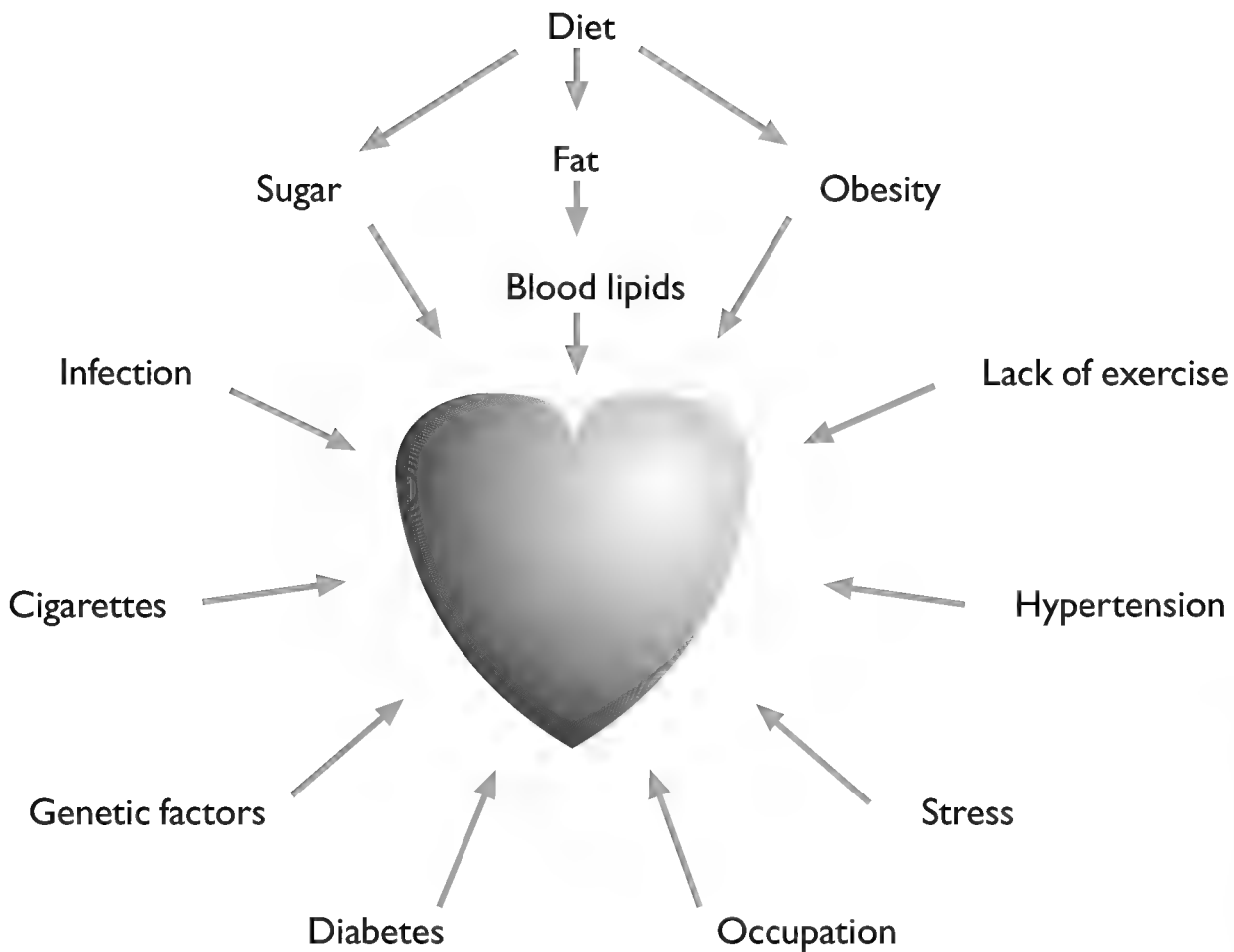
Graph to show bronchitis death rates according to smoking habits



Graph to show death rates from lung cancer according to smoking habits







## Questions on heart disease risk factors chart

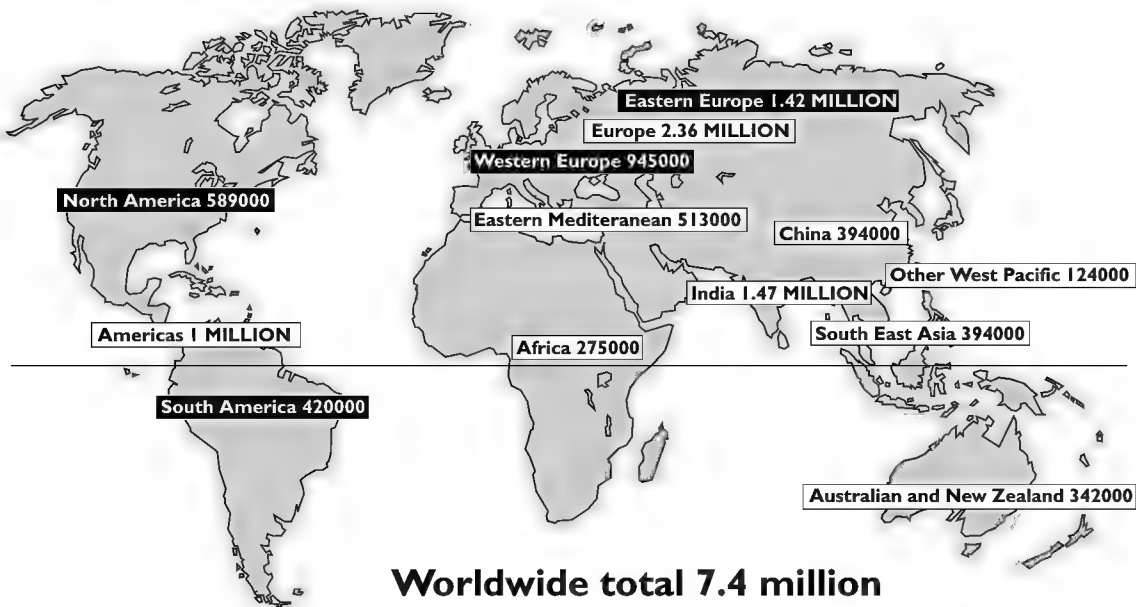
| Age       | Sex                  | Weight                    | % Animal Fat in Diet |         |
|-----------|----------------------|---------------------------|----------------------|---------|
| 10-20     | Female under 40      | More than 2kg below ideal | No animal fat        |         |
| 21-30     | Female under 40-50   | Within 2kg of ideal       | 10% animal fat       |         |
| 31-40     | Female under over 50 | 15kg over ideal           | 20% animal fat       |         |
| 41-50     | Male                 | 20kg over ideal           | 30% animal fat       |         |
| 51-60     | Stocky male          | 25kg over ideal           | 40% animal fat       |         |
| 61 & over | Bald stocky male     | 30kg over ideal           | 50% animal fat       | Total 1 |
|           | +                    | +                         | +                    | =       |

| Exercise                     | Tobacco smoking       | History of heart disease | Blood pressure            | +       |
|------------------------------|-----------------------|--------------------------|---------------------------|---------|
| Hard manual job & exercise   | Non smoker            | None                     | Upper reading 100         |         |
| Manual job & medium exercise | Cigar or pipe smoker  | 1 relative over 60       | Upper reading 120         |         |
| Office job & hard exercise   | 10 cigs. aday or less | 2 relatives over 60      | Upper reading 140         |         |
| Office job & medium exercise | 20 cigarettes aday    | 1 relative under 60      | Upper reading 160         |         |
| Office job & light exercise  | 30 cigarettes aday    | 2 relatives under 60     | Upper reading 180         |         |
| No exercise                  | 40 cigarettes aday    | 3 relatives under 60     | Upper reading 200 or more | Total 2 |
|                              | +                     | +                        | +                         | =       |

The higher the total the higher the risk of CHD

Grand Total = \_\_\_\_\_

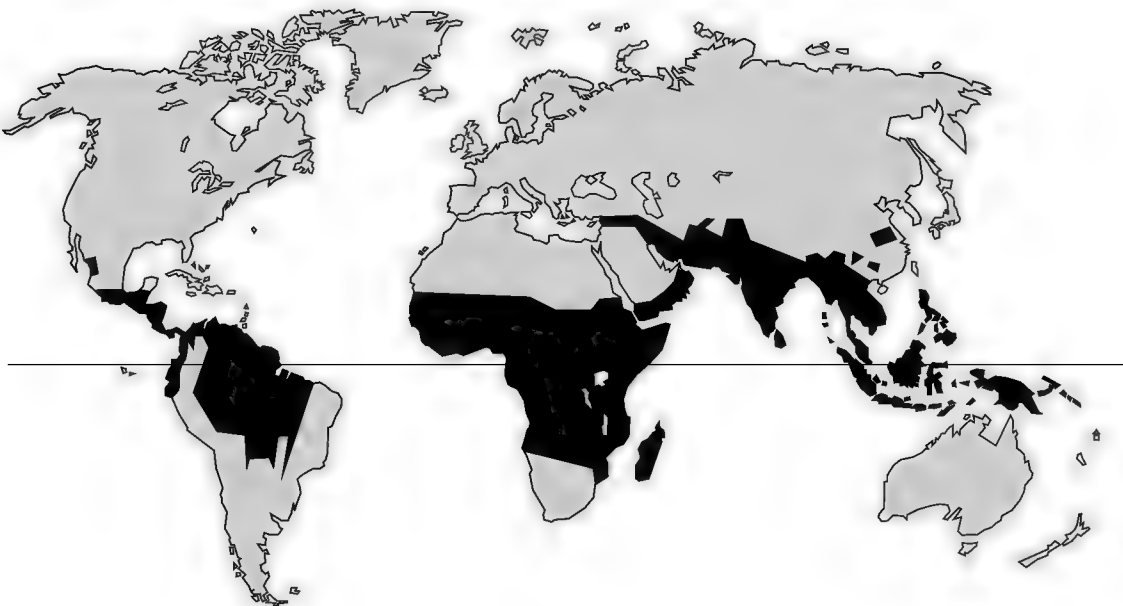
## Global distribution of deaths from Coronary Heart Disease (CHD) 1999

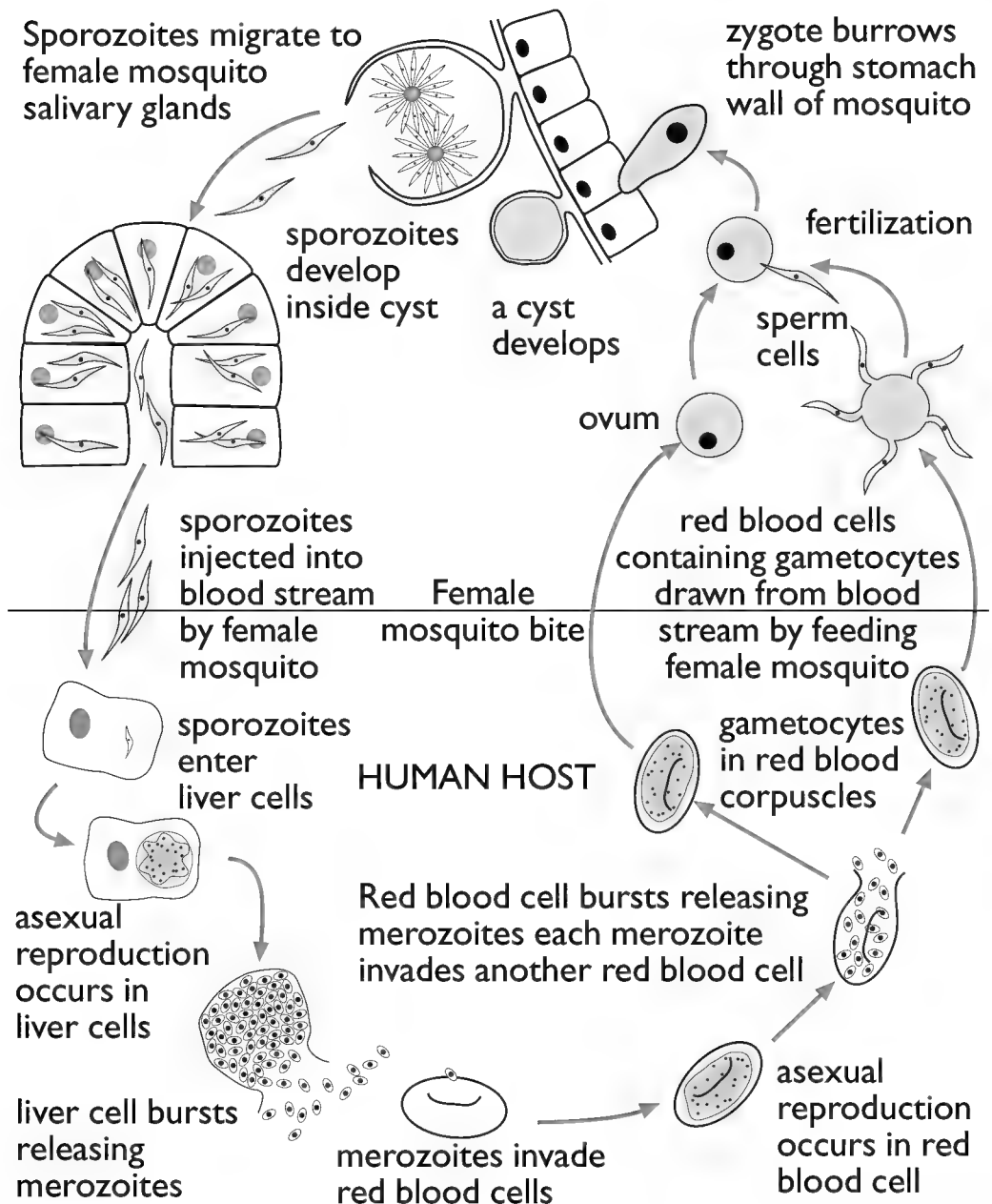


# **The World Health Organisation defines health as:**

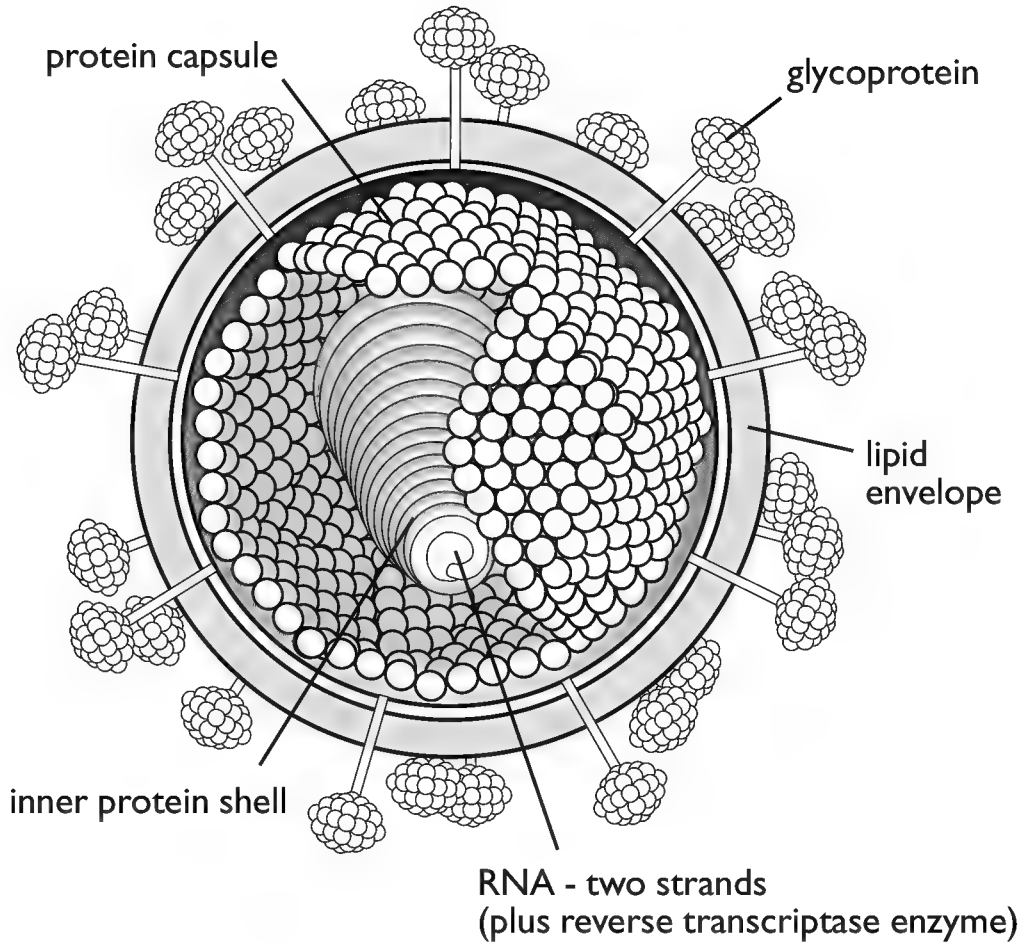
*“a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity.”*

## Worldwide distribution of malaria

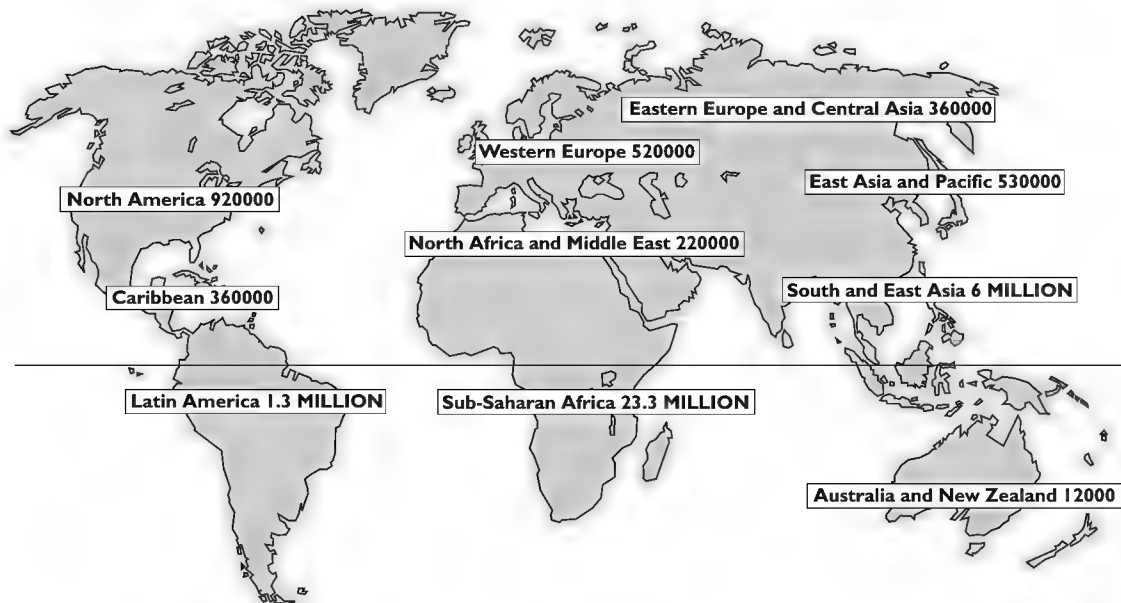




## Human Immunodeficiency Virus



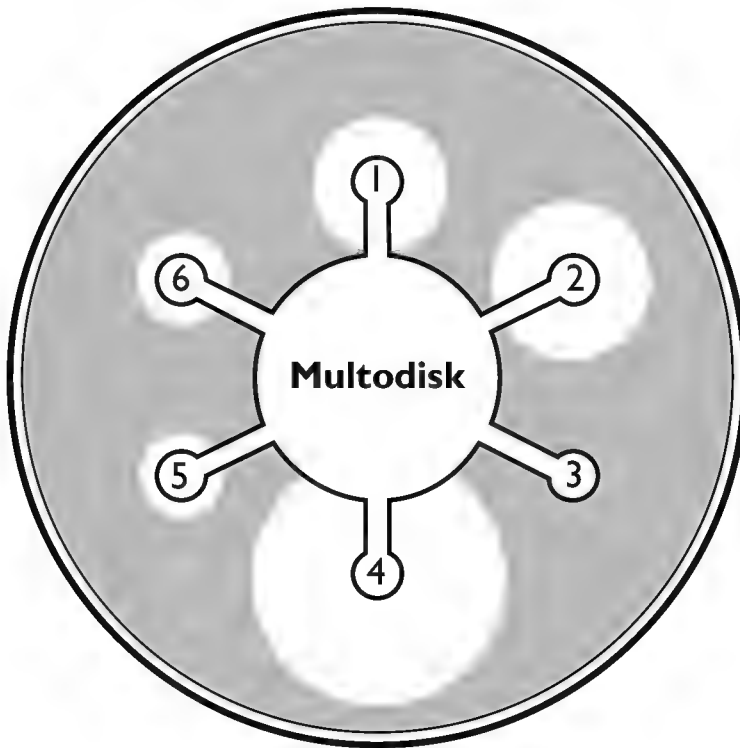
## Worldwide distribution of adults and children estimated to be living with HIV/AIDS 1999,



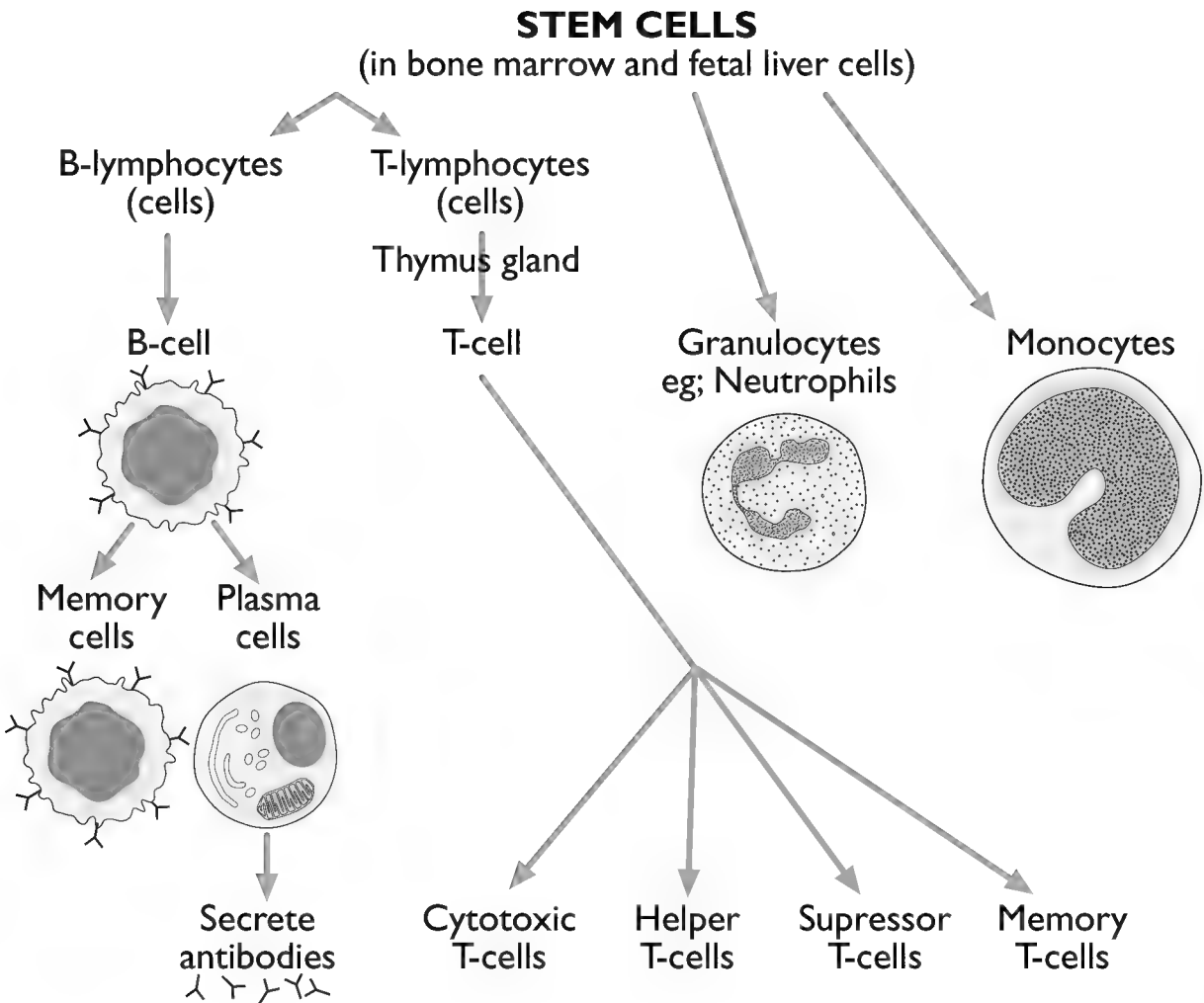
|                                             |              |
|---------------------------------------------|--------------|
| People living with HIV/AIDS                 | 33.6 million |
| New HIV infections in 1999                  | 5.6 million  |
| Deaths due to HIV/AIDS in 1999              | 2.6 million  |
| Cumulative number of deaths due to HIV/AIDS | 16.3 million |



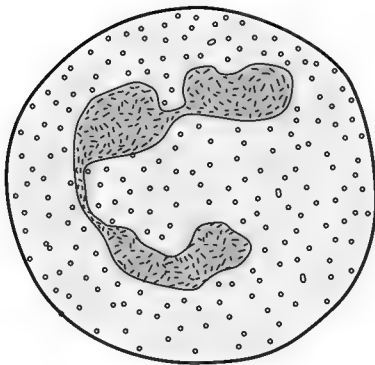
**Diagram to show action of specific antibiotics on a bacterial culture**



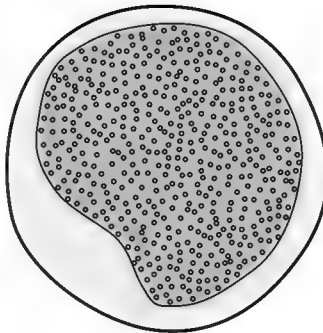
- 1 Tetracycline
- 2 Chloraphenol
- 3 Erythromycin
- 4 Sulphafurazole
- 5 Penicillin G
- 6 Streptomycin



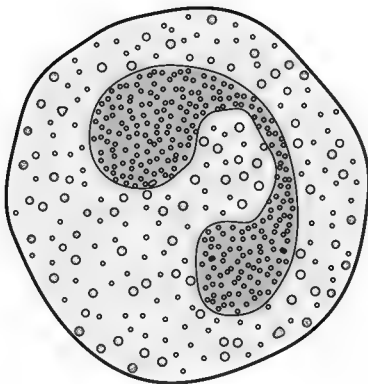
## Phagocytes and lymphocytes



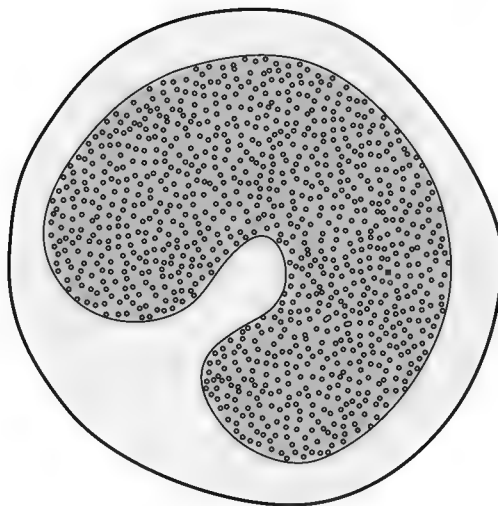
Neutrophil



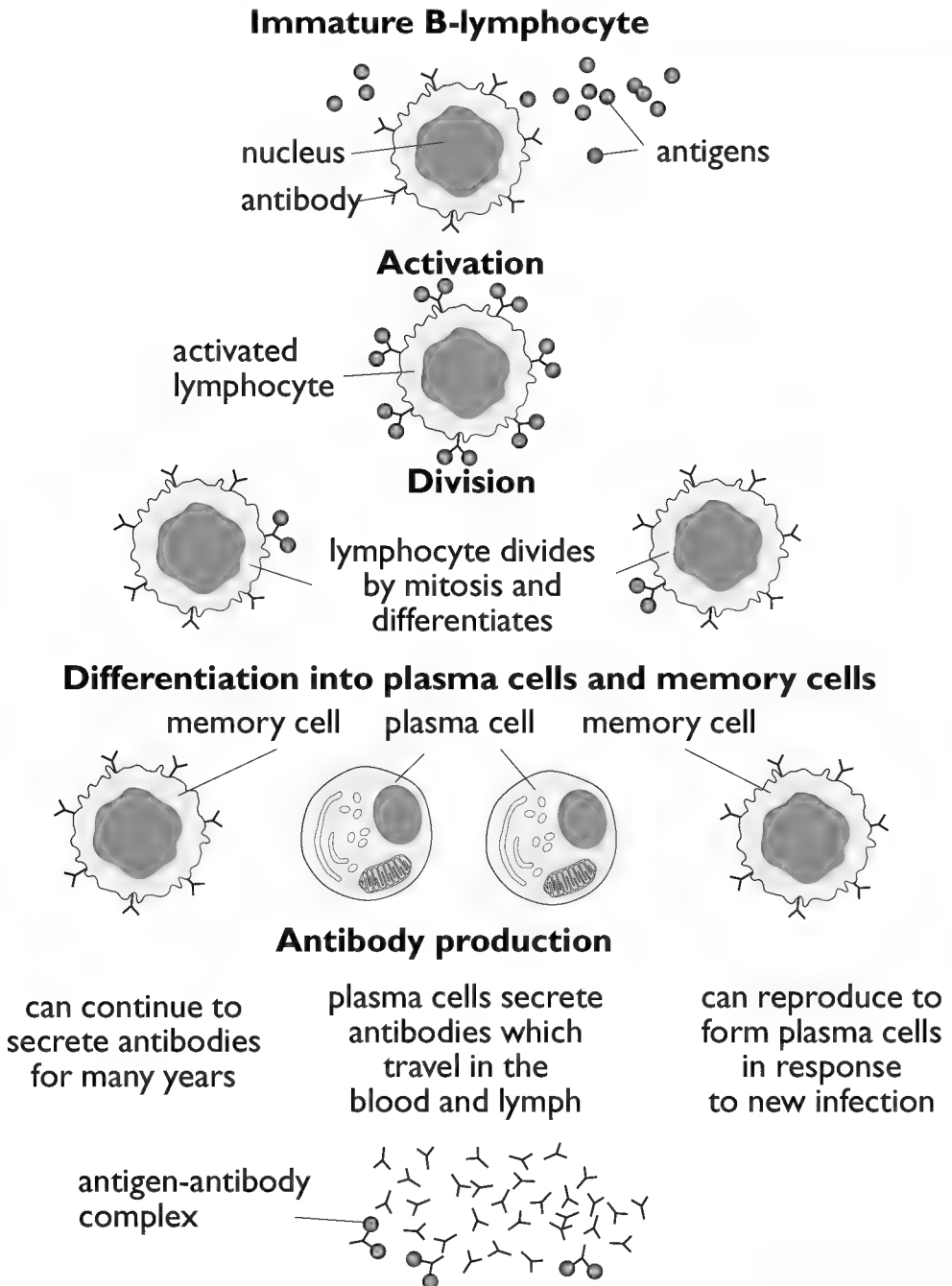
Lymphocyte



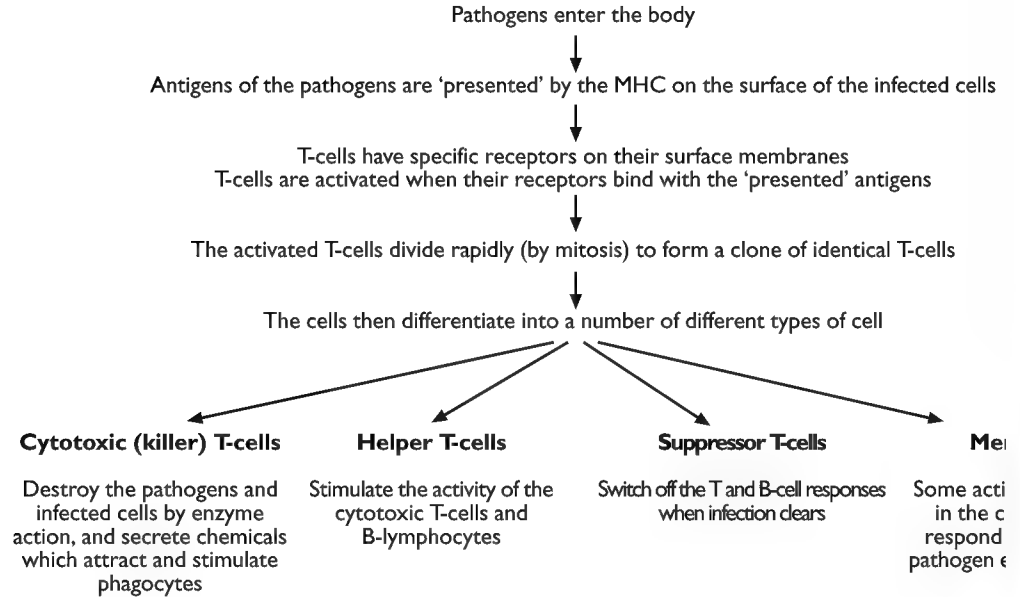
Eosinophil

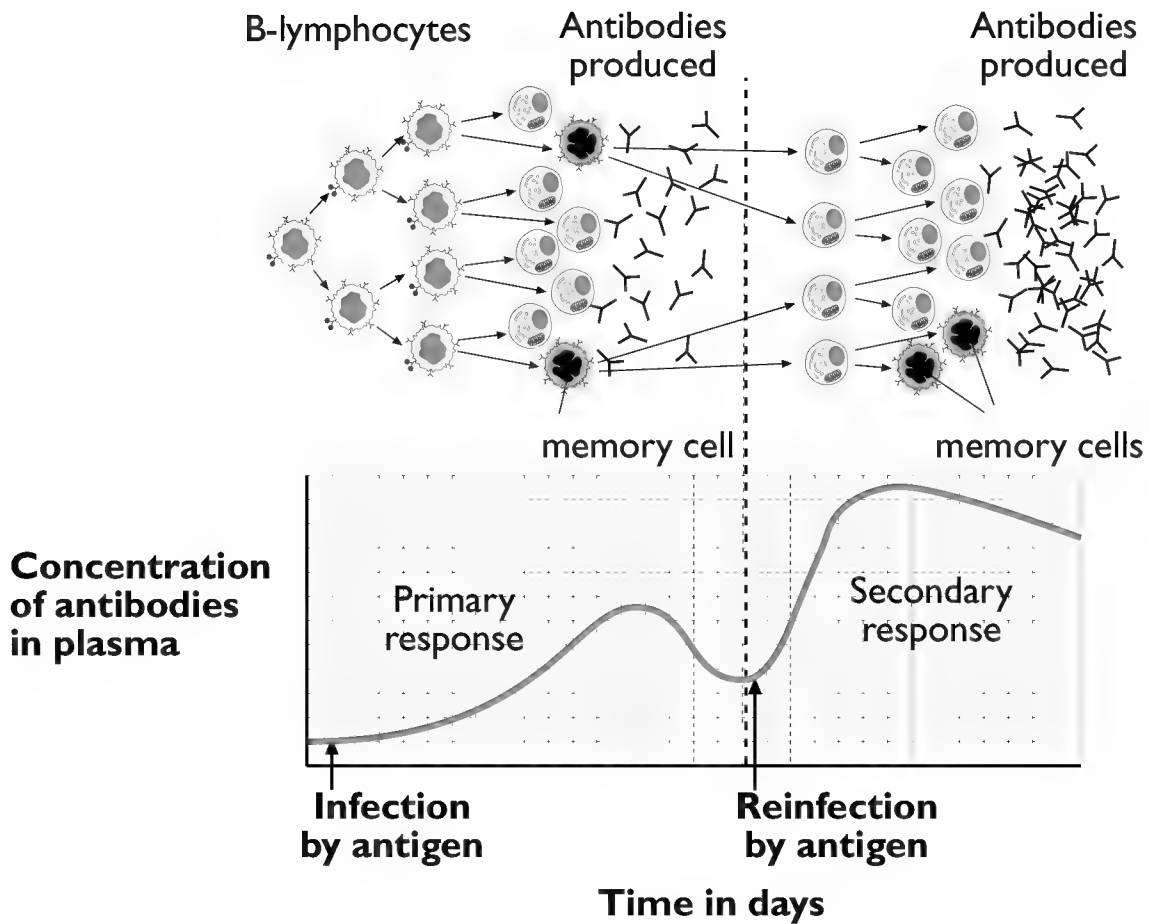


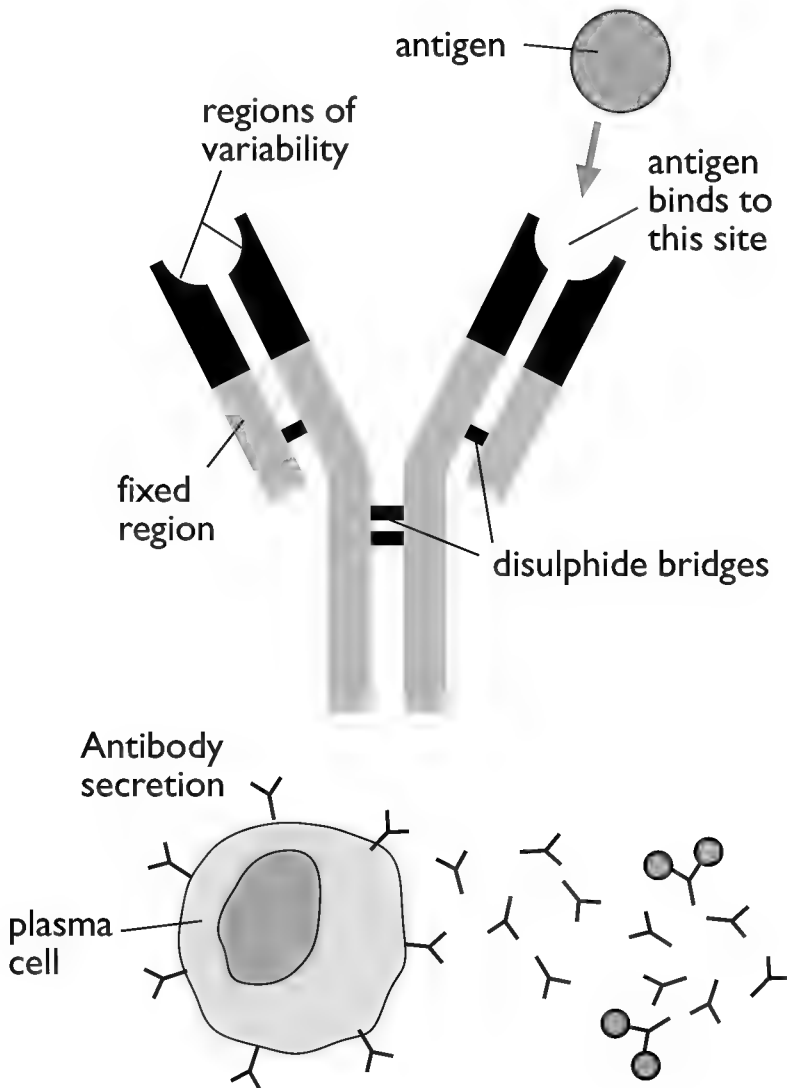
Monocyte



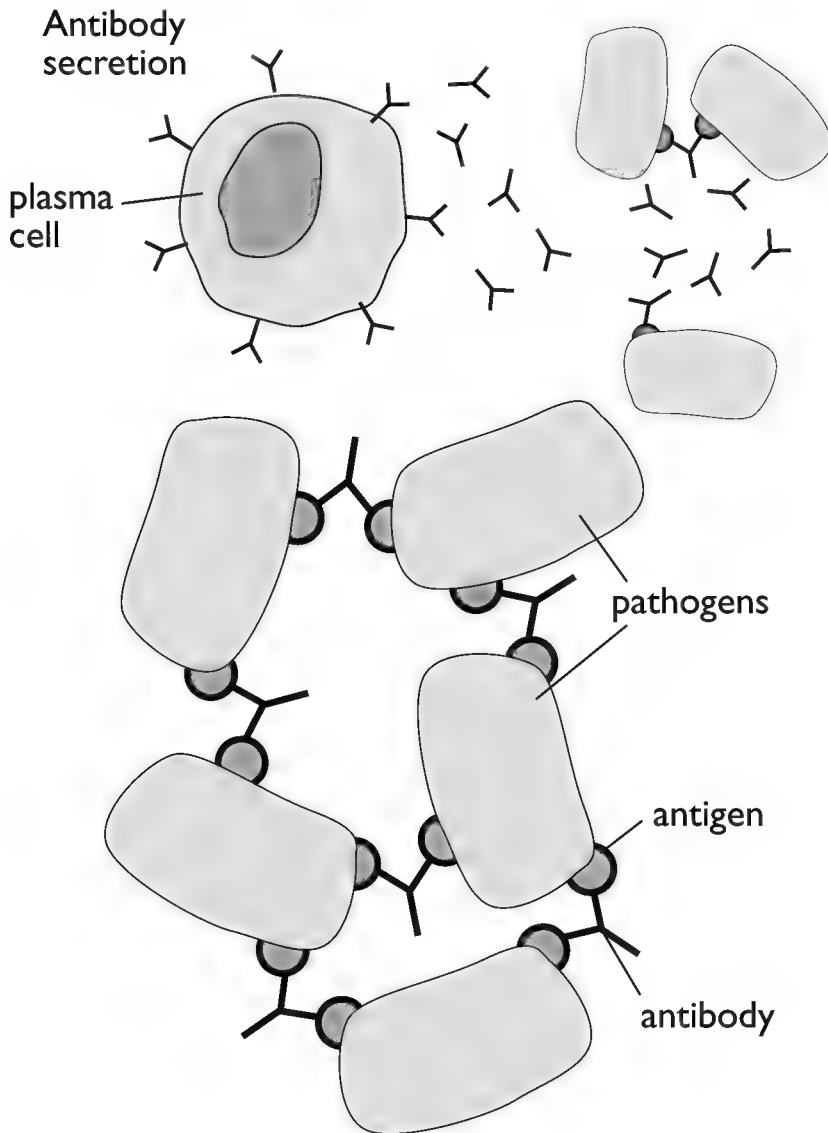
## Cellular response to infection - T-lymphocytes (T-cells)







## Antibodies bind pathogens together



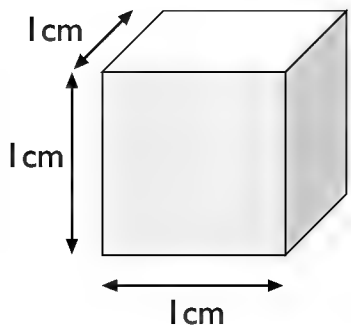
Pathogens trapped ready for phagocytosis



Surface area =  $6\text{cm}^2$

Volume =  $1\text{cm}^3$

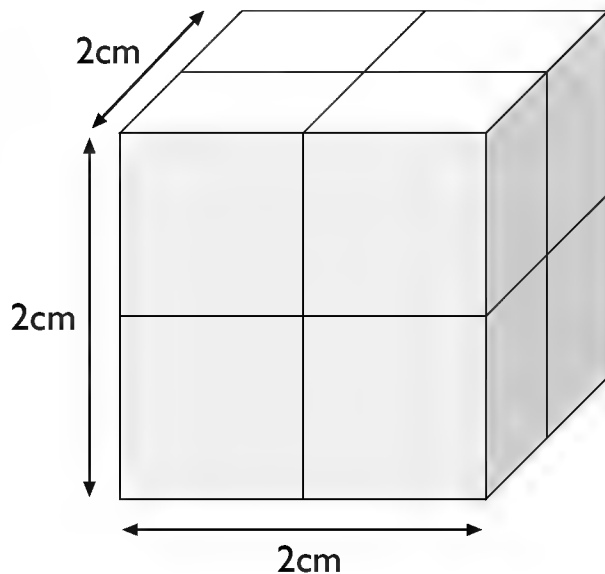
Surface area to volume =  $6:1 = 6$

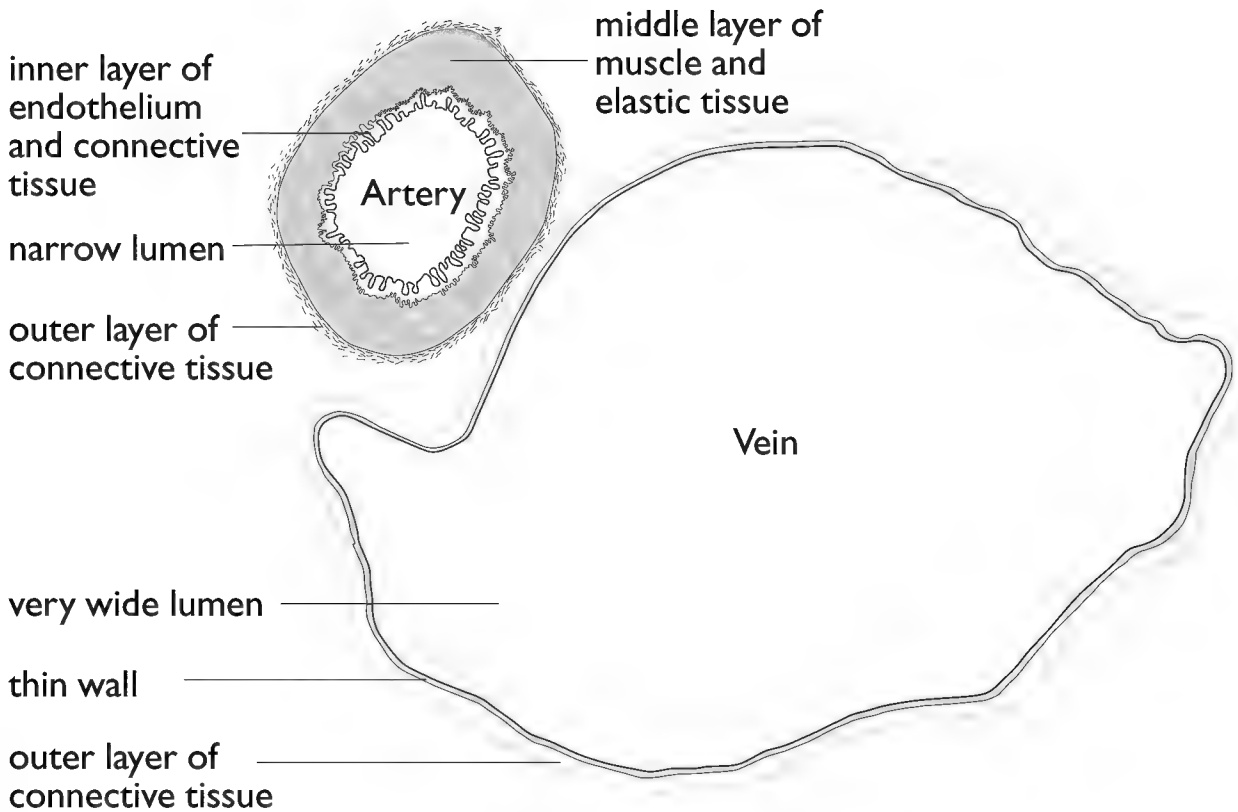


Surface area =  $24\text{cm}^2$

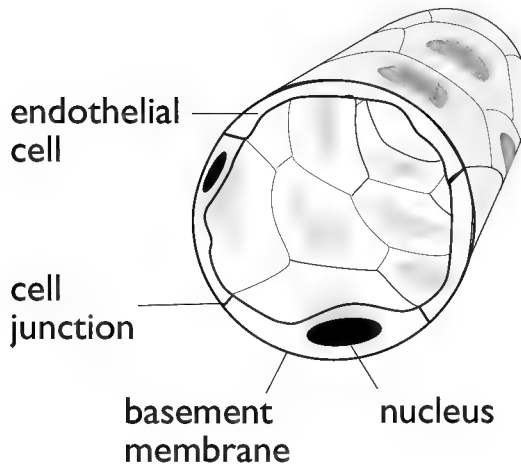
Volume =  $8\text{cm}^3$

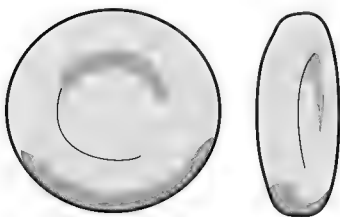
Surface area to volume =  $24:8 = 3$





## Structure of a typical Capillary

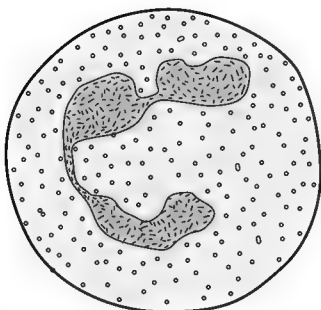




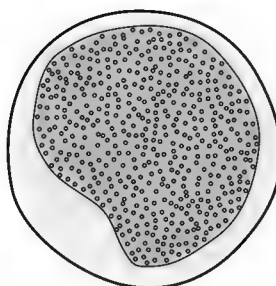
Red cell



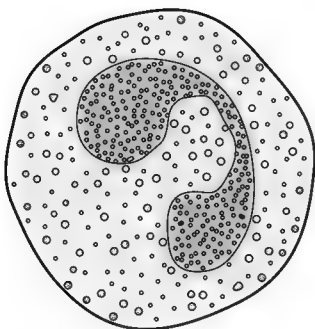
Platelets



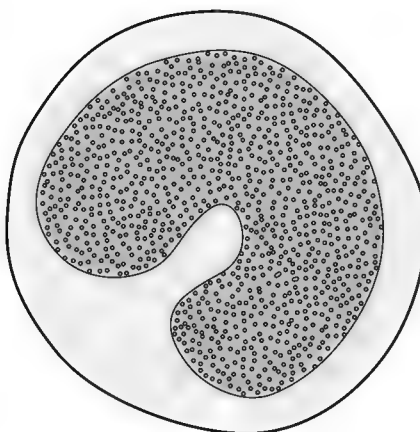
Neutrophil



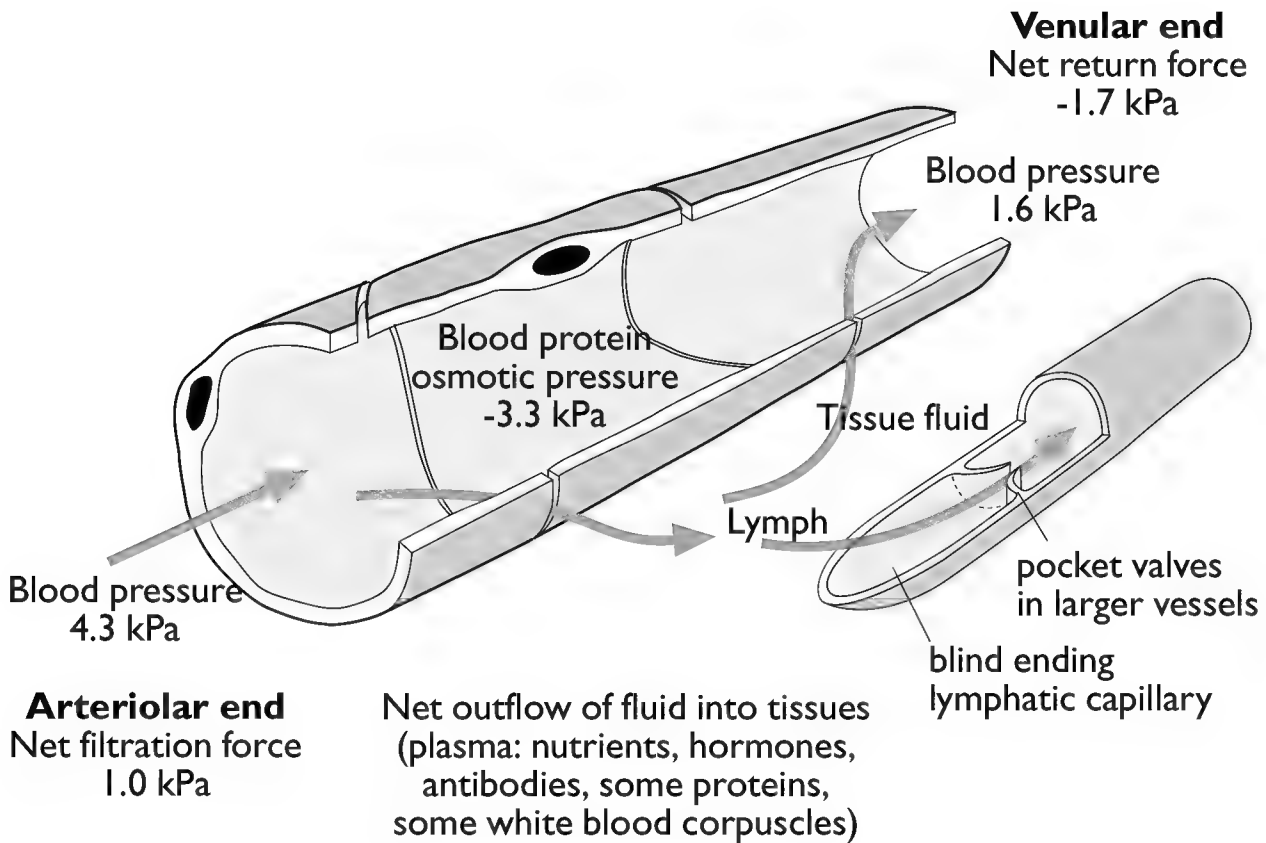
Lymphocyte



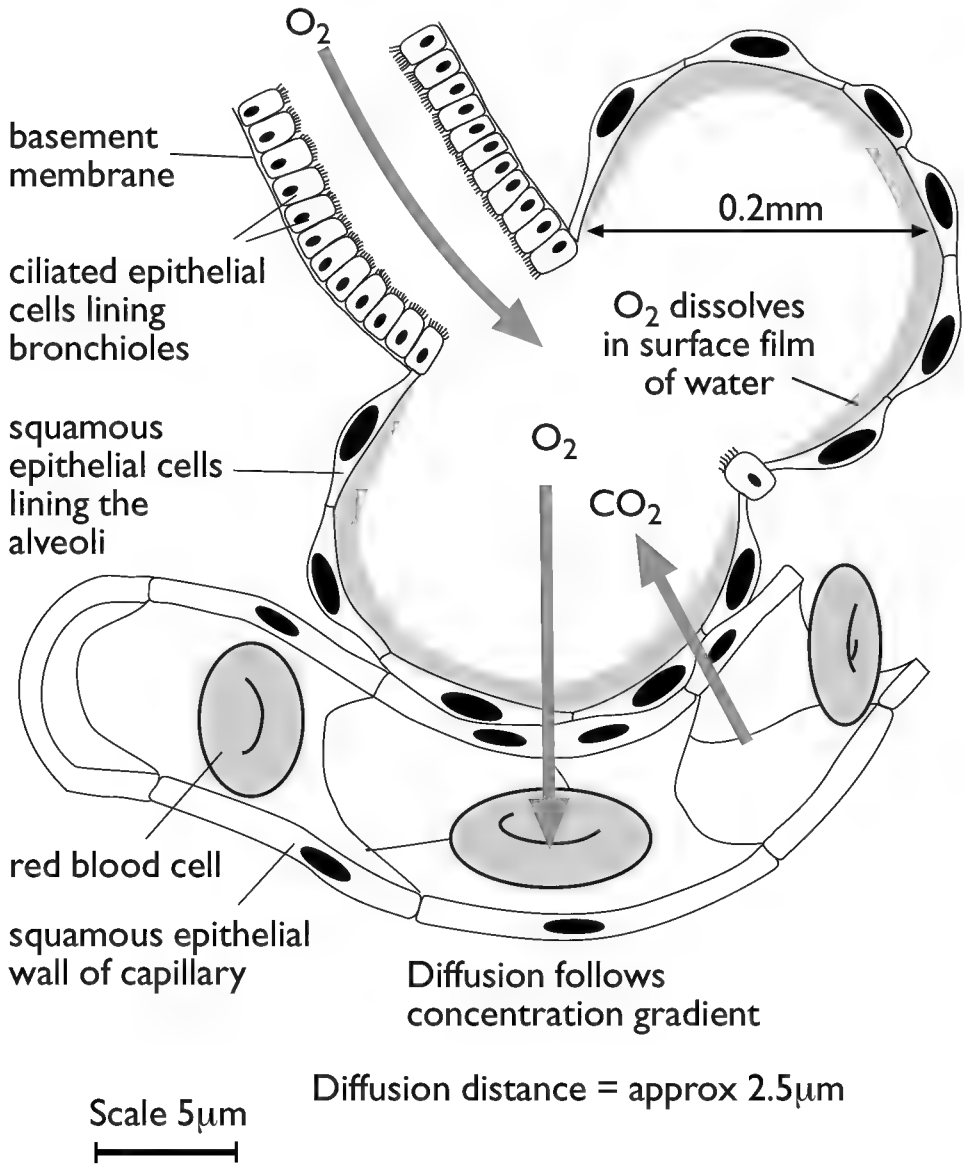
Eosinophil



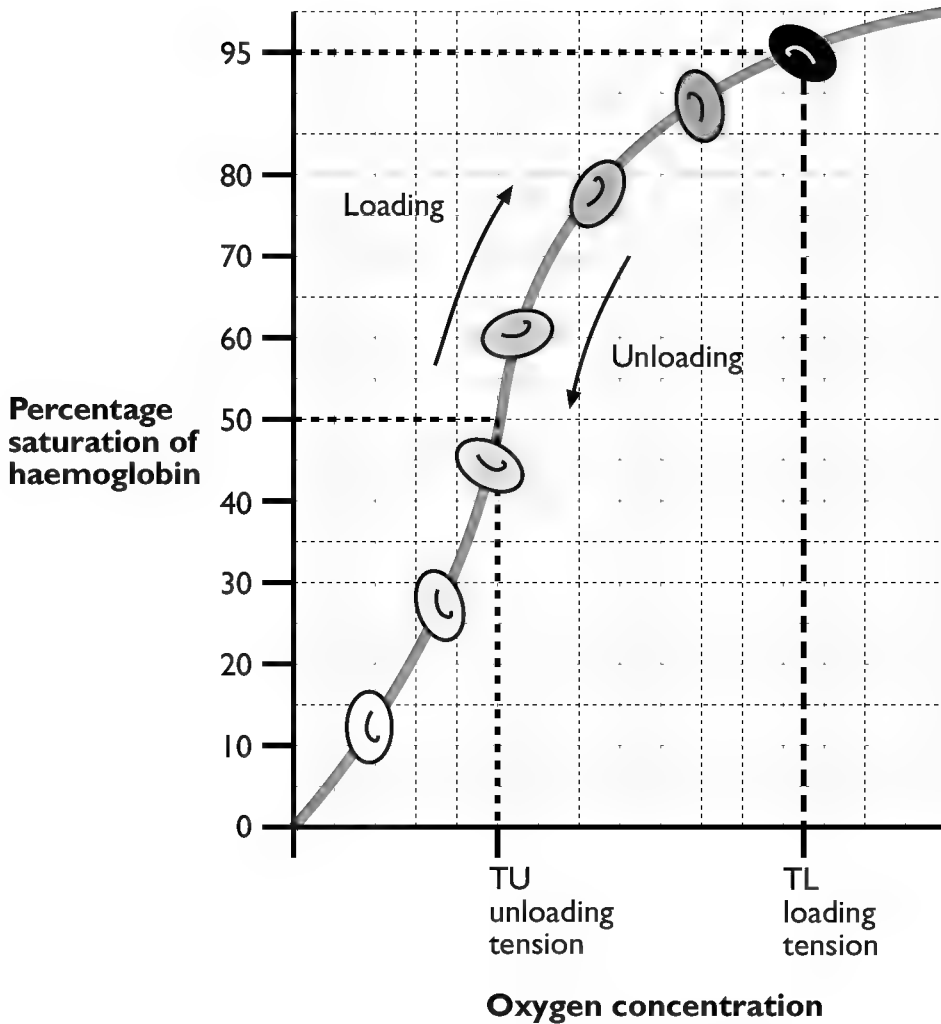
Monocyte



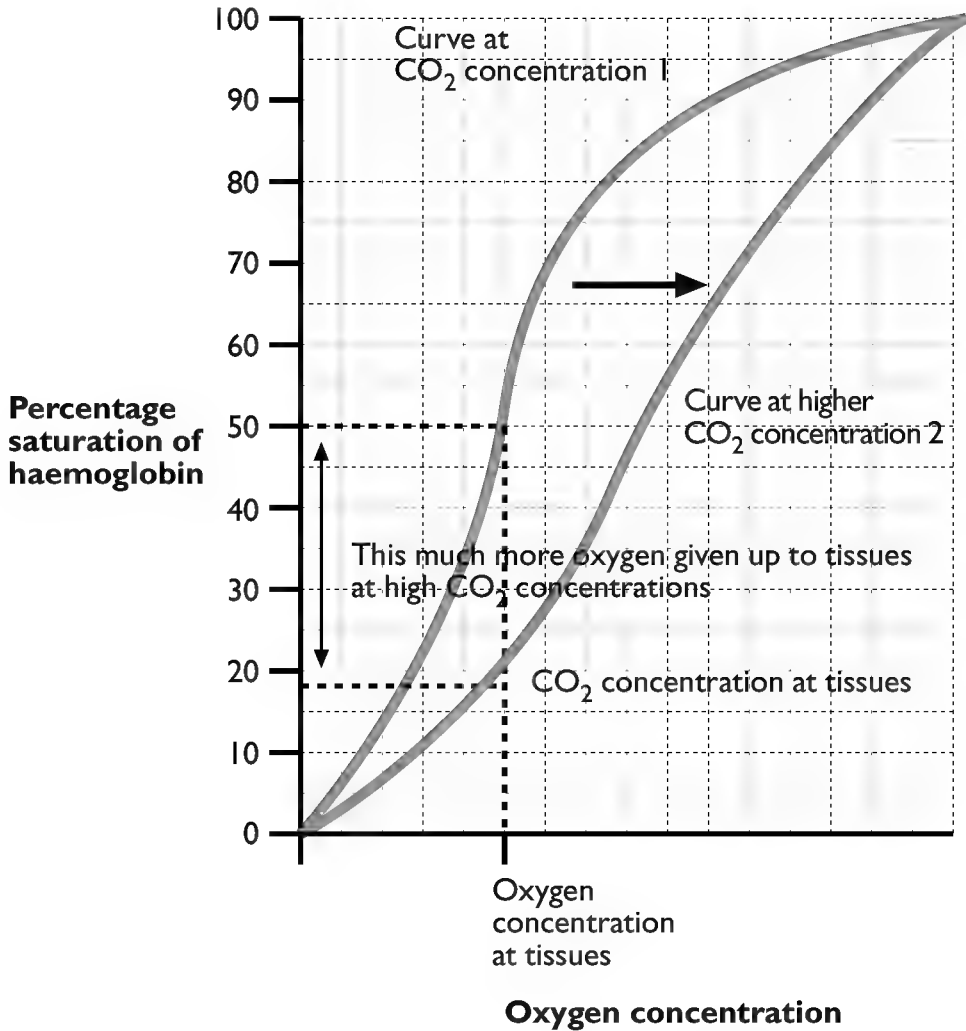
## Diagram of Alveoli and Associated Capillaries



## Normal dissociation curve

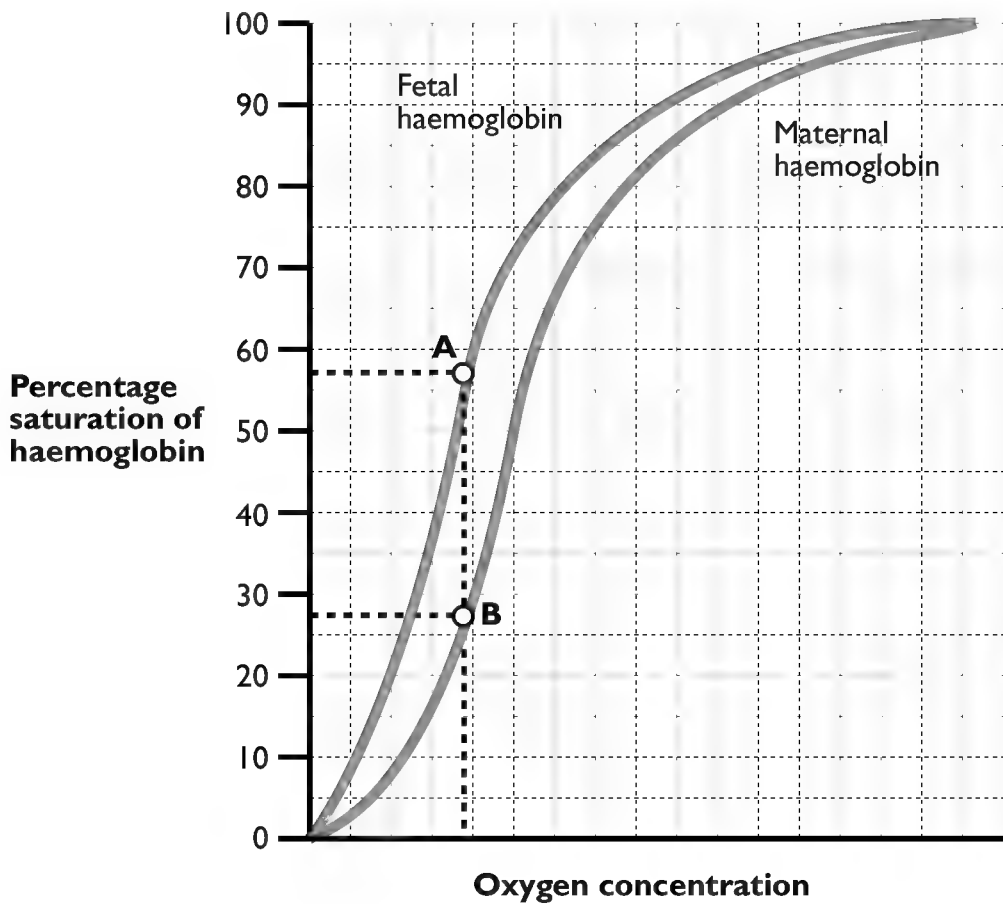


This basic type of curve is altered with differing conditions



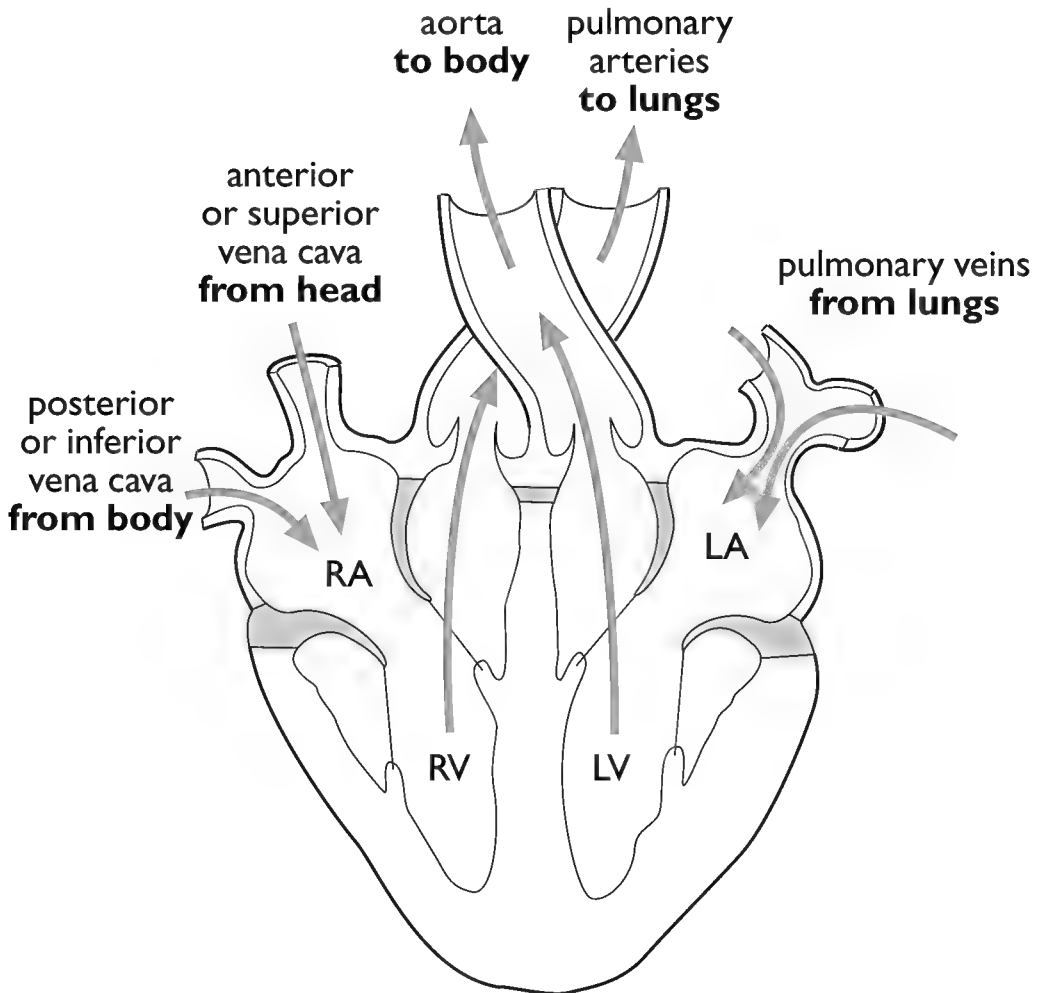


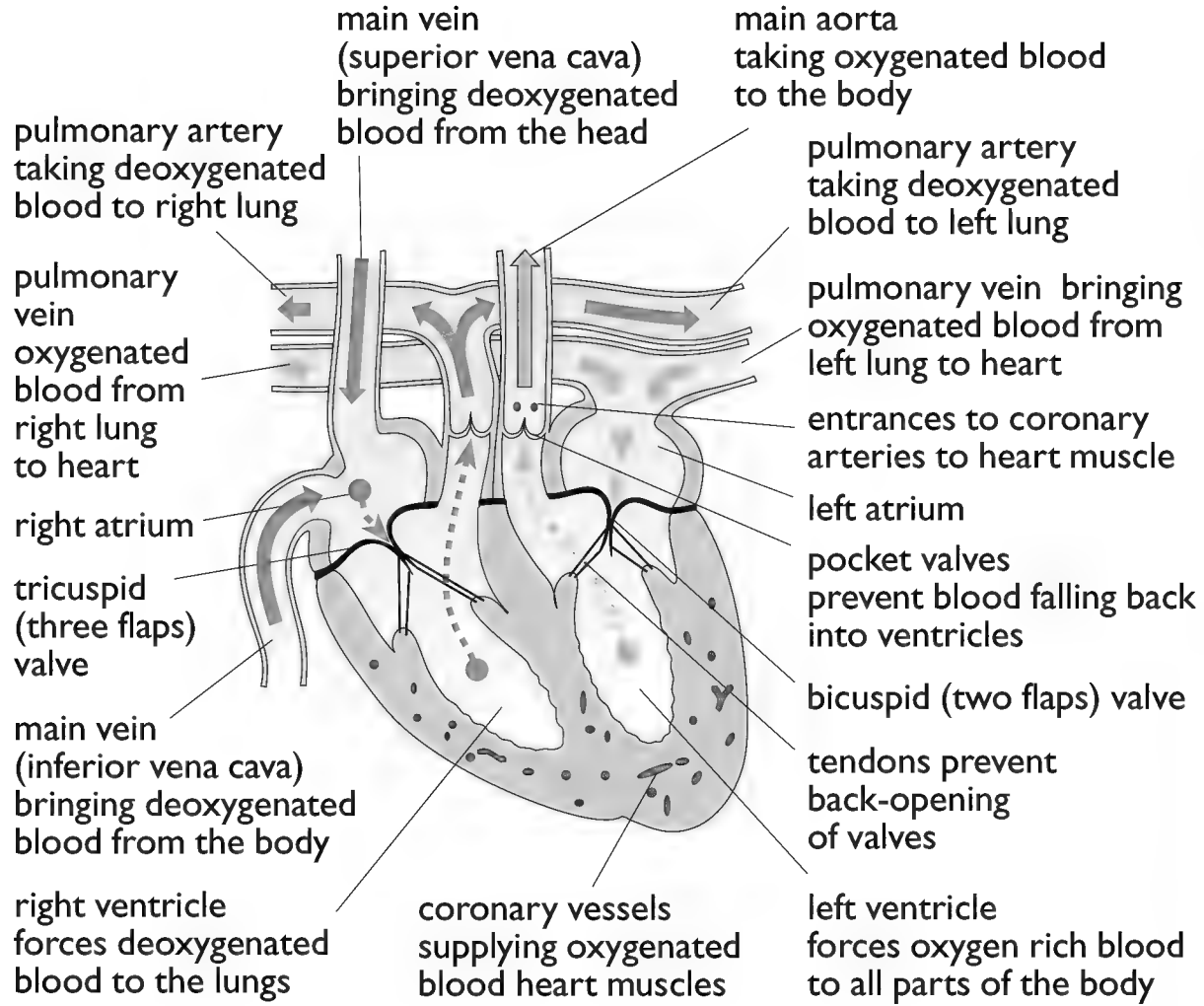
Fetal haemoglobin dissociation curve



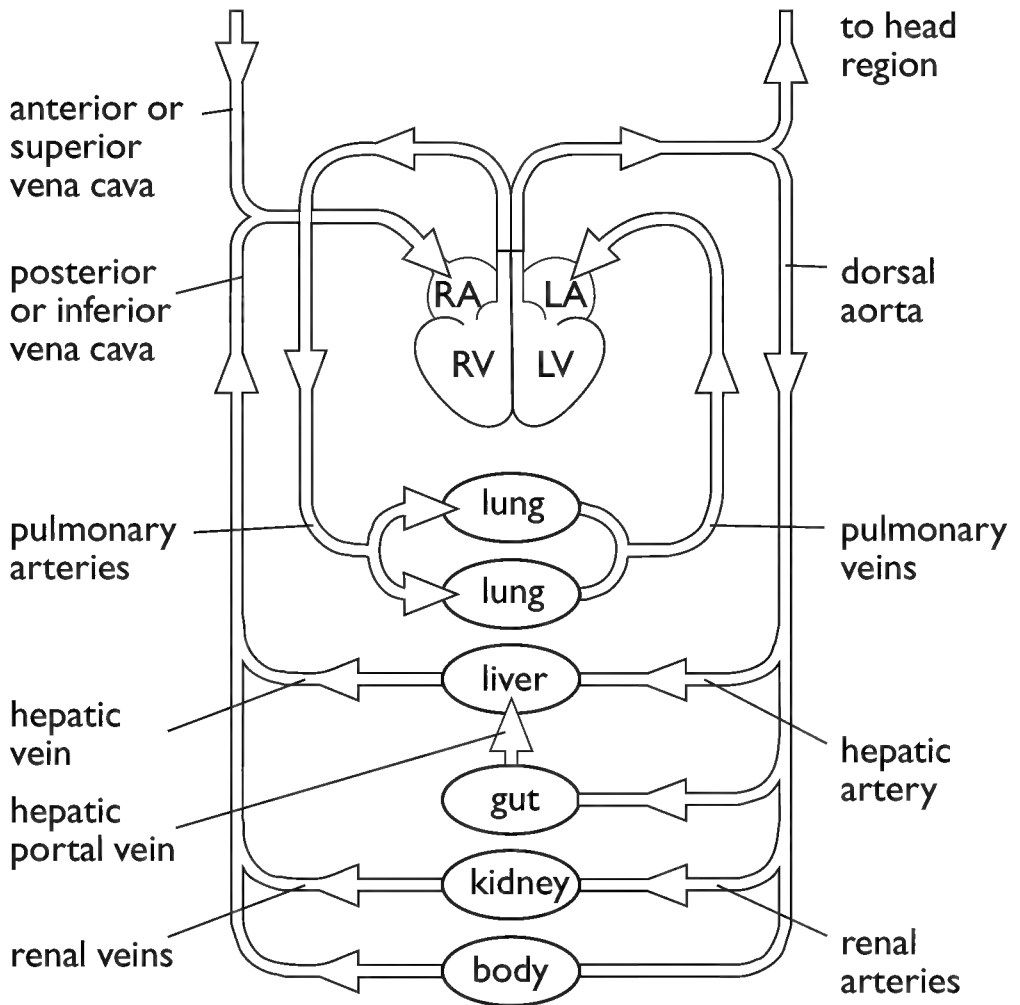
## Diagram of heart structure

Diagram of heart structure



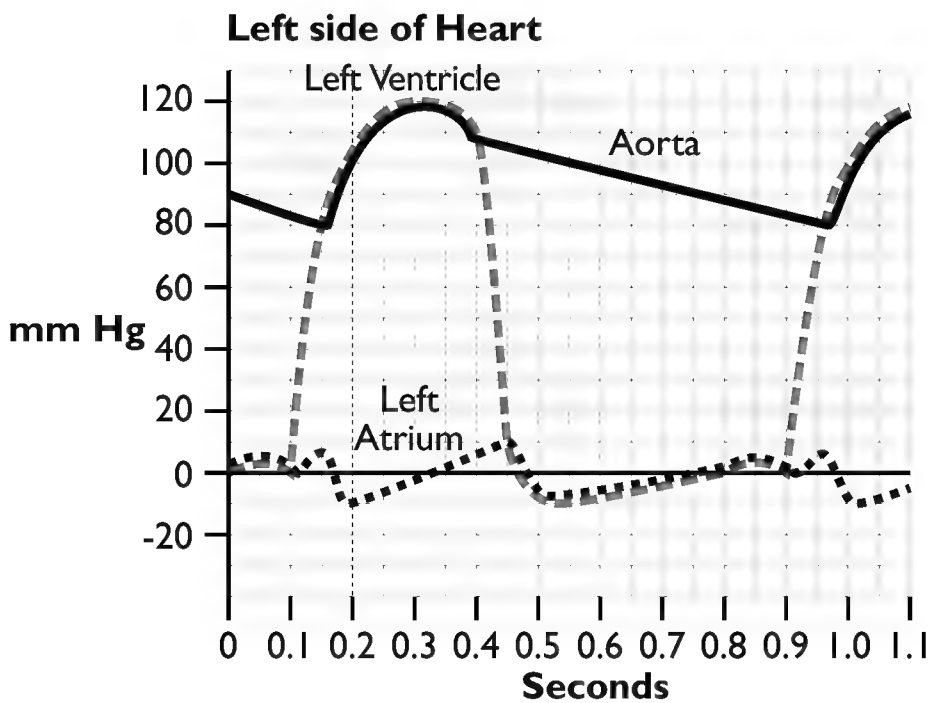
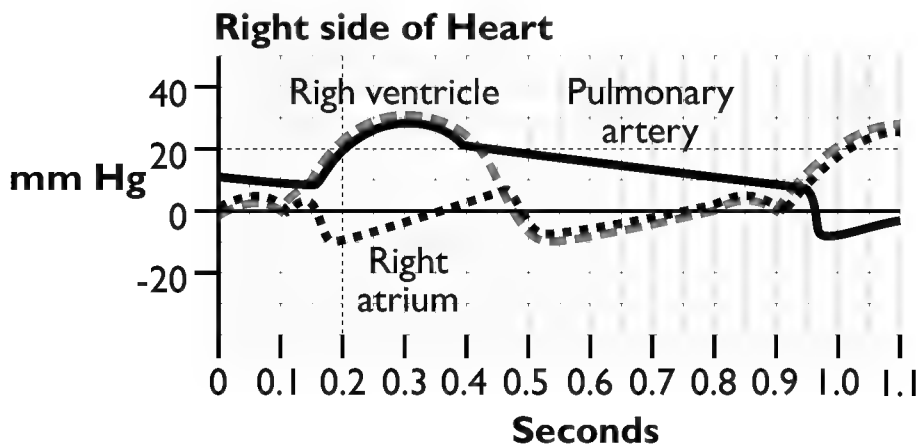


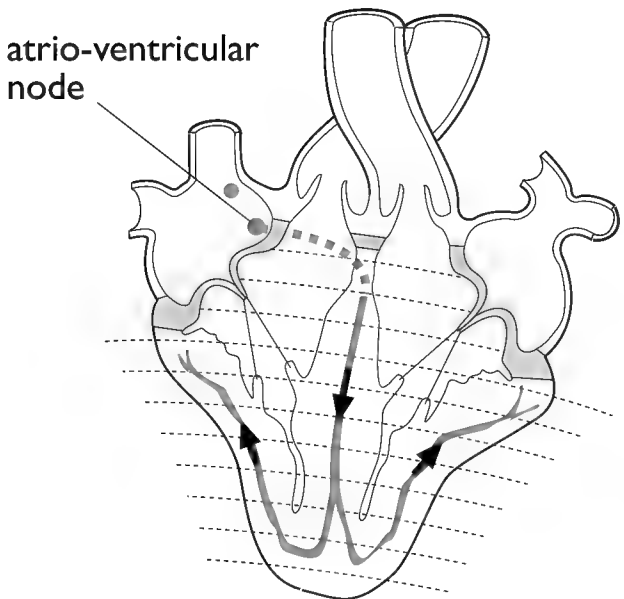
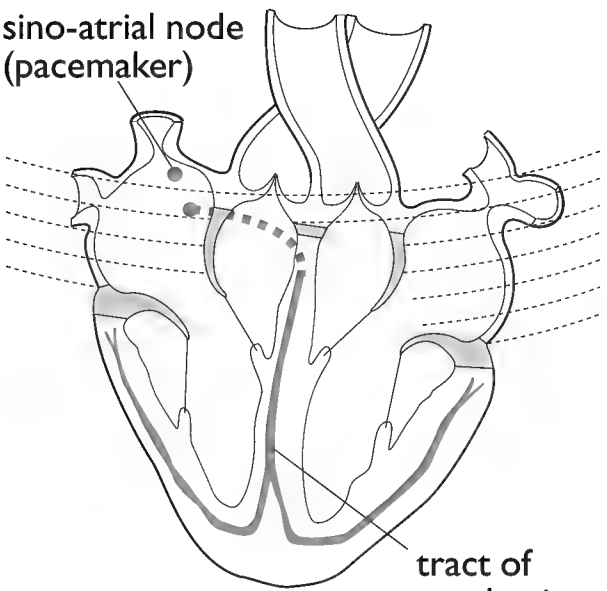
## Closed double circulation diagram

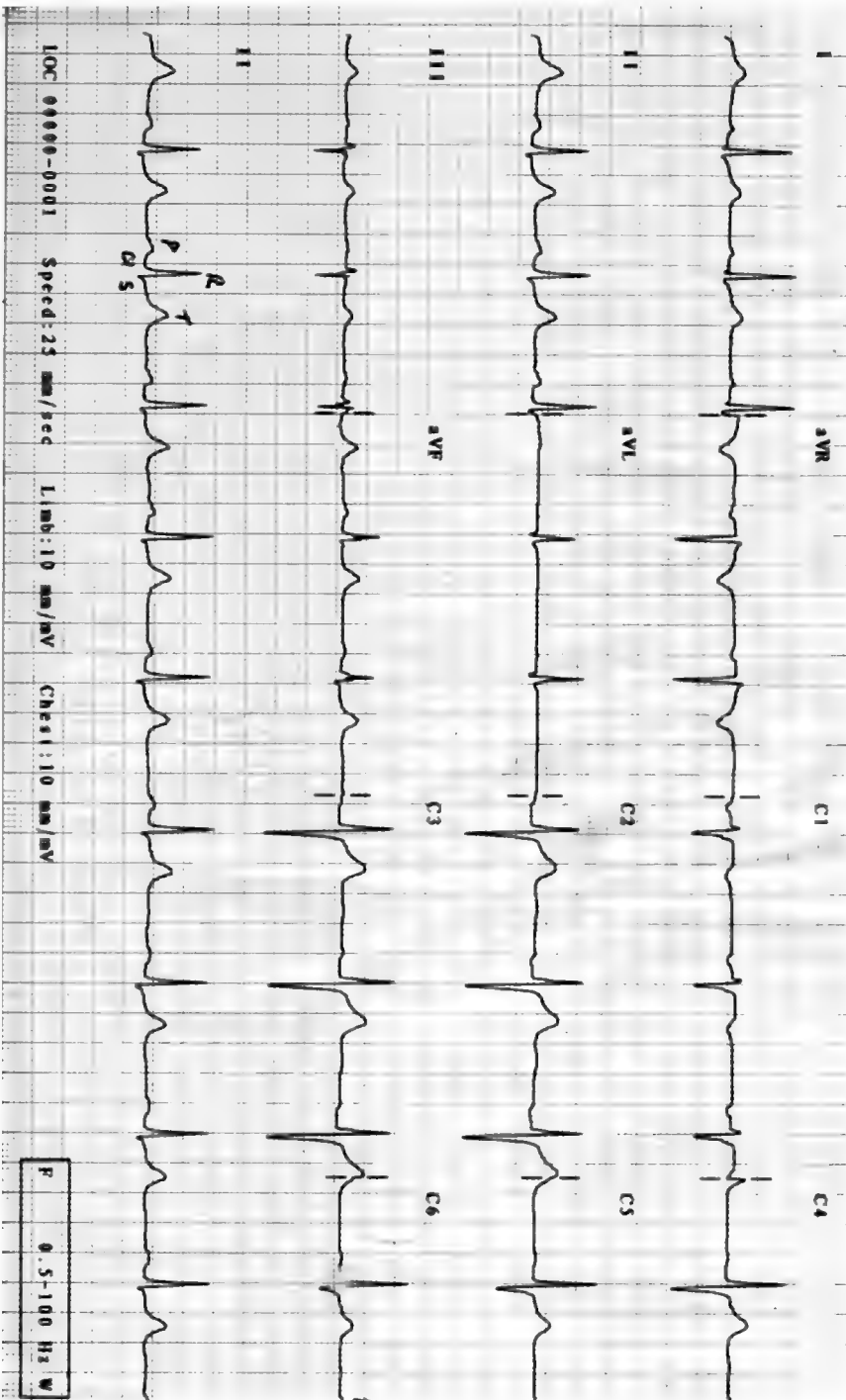


## Graph - chart of cardiac cycle

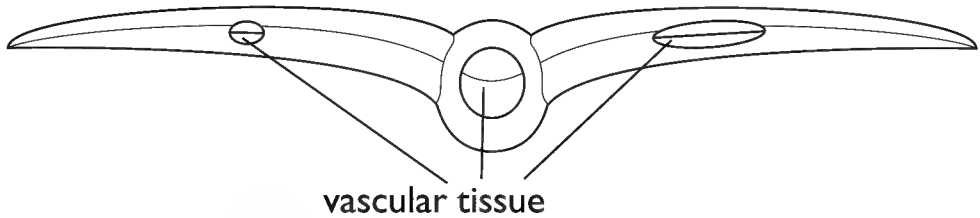
Pressure (mm Hg)



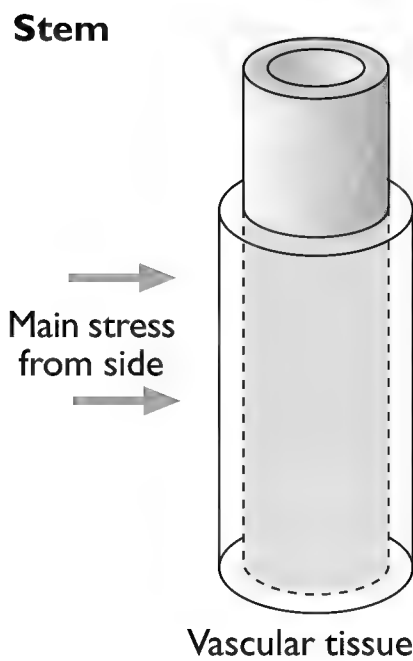




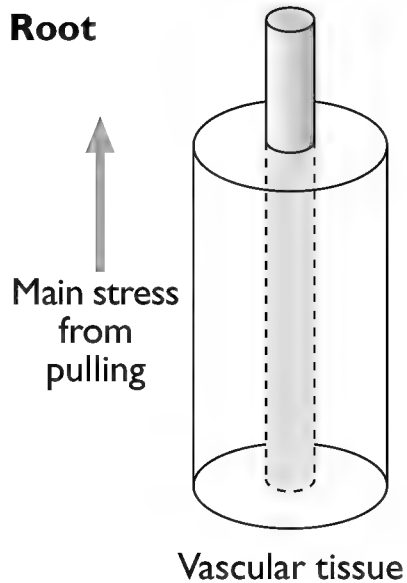
## Low power plan leaf (section)



### Stem

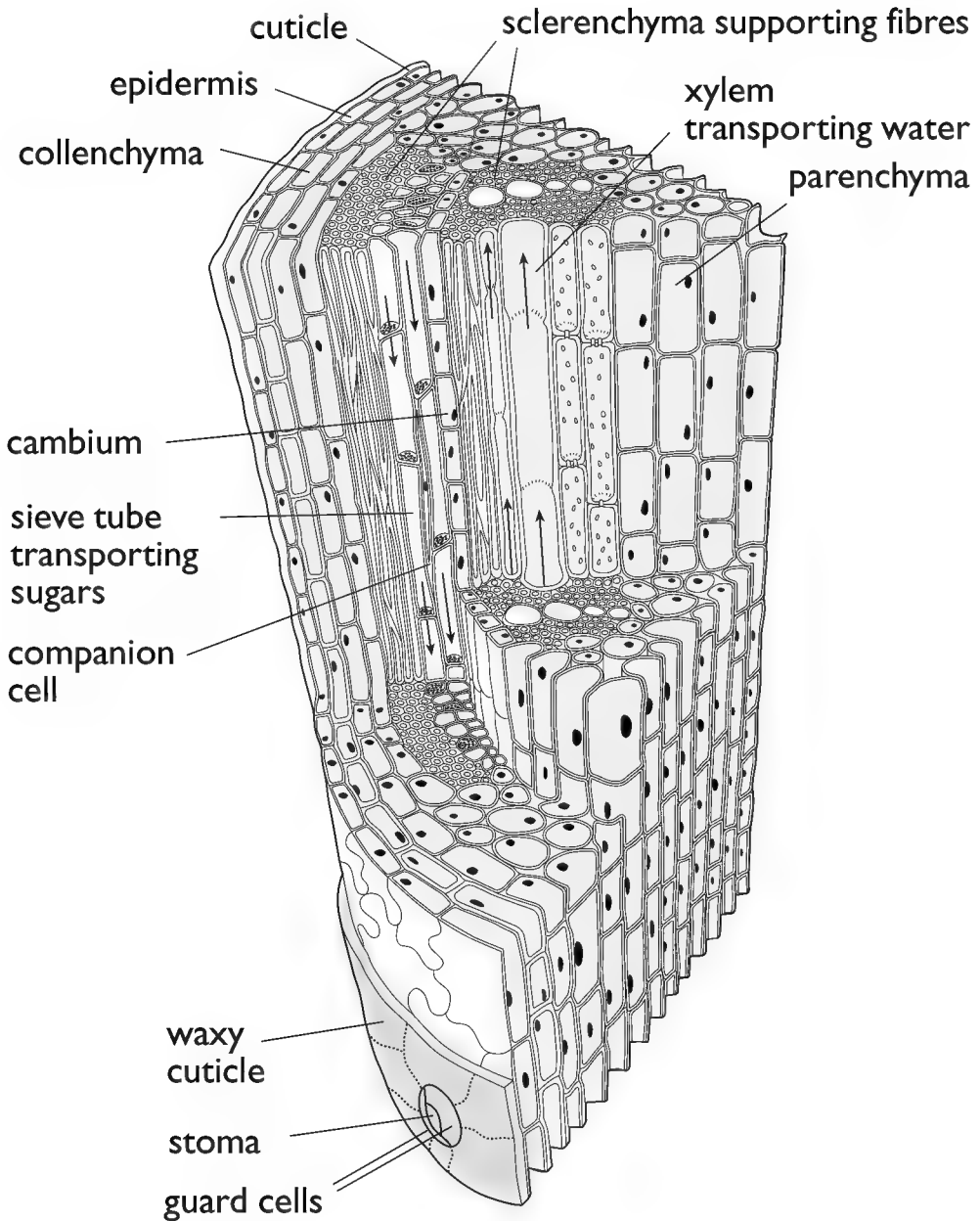


### Root

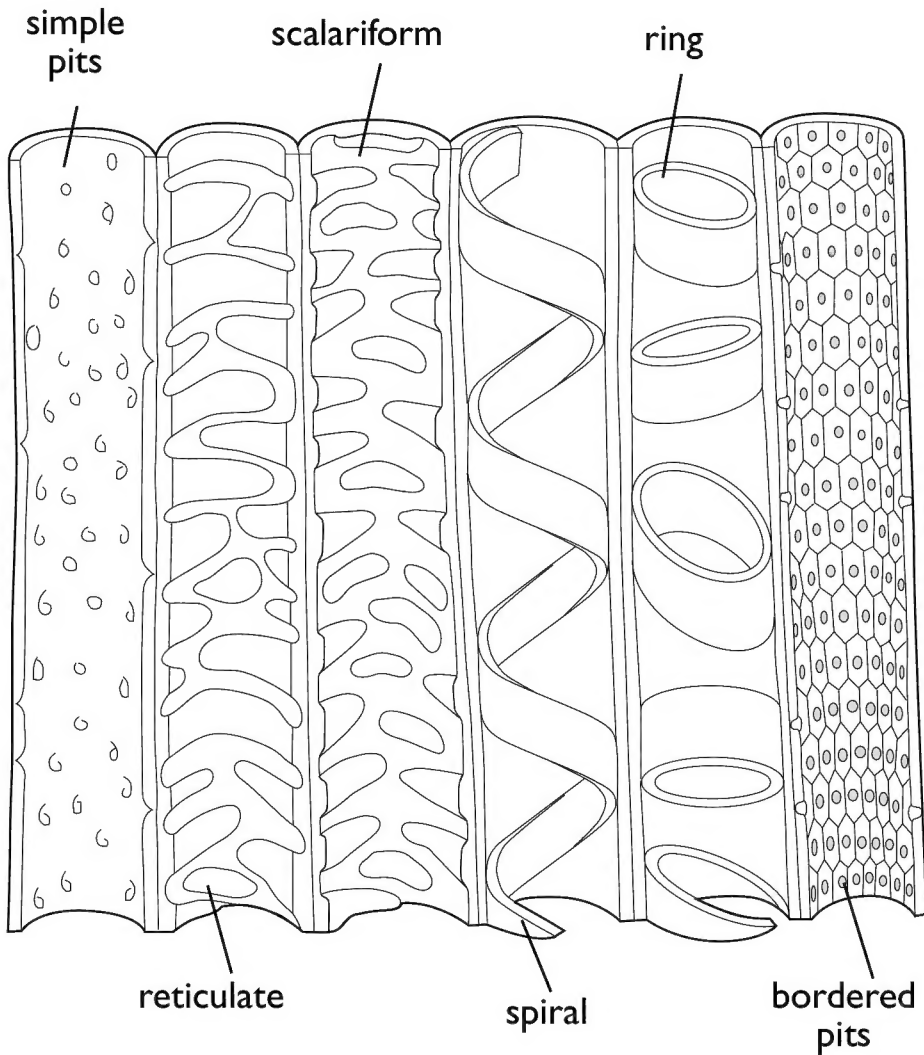


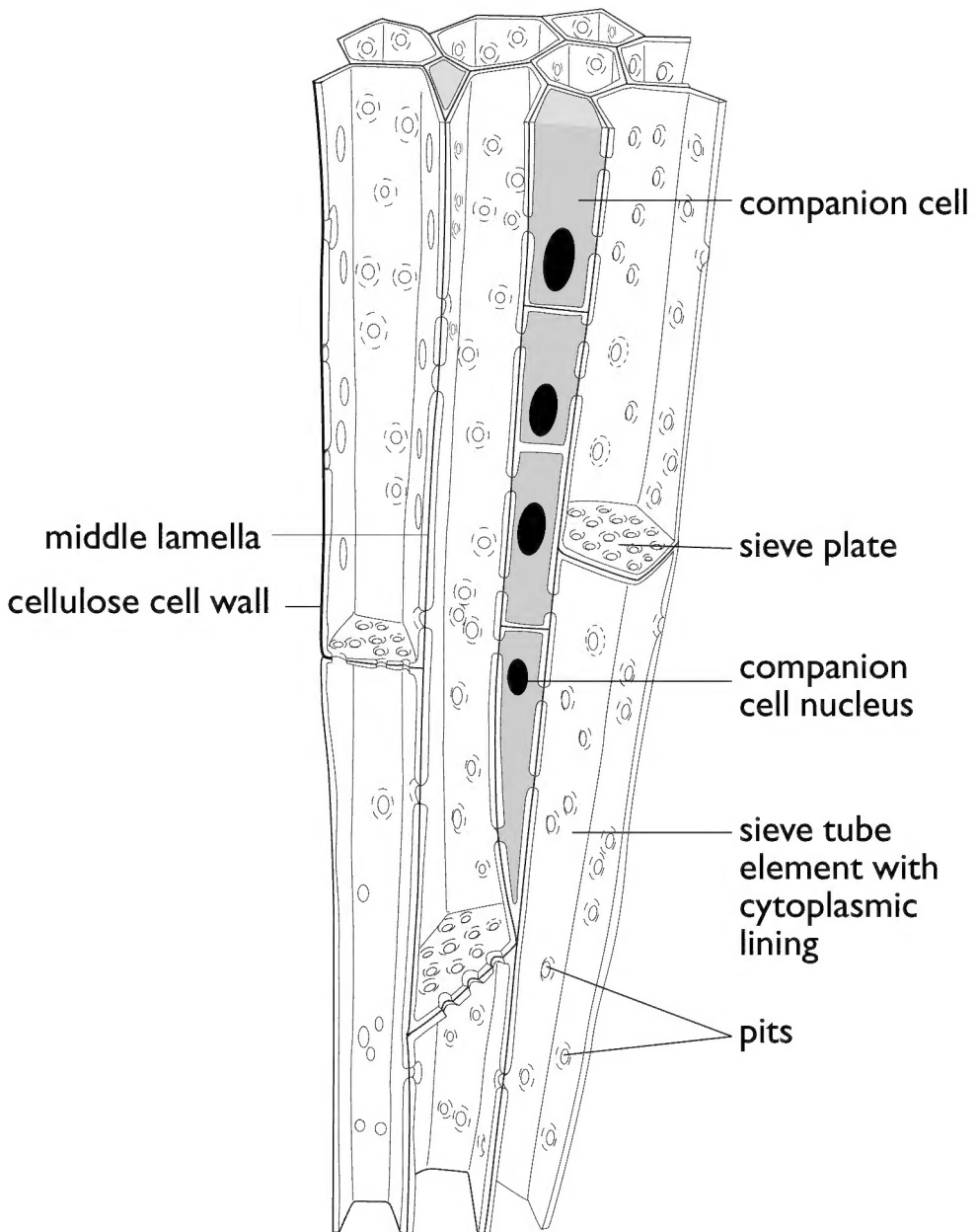


Xylem and phloem T.S. and L.S.



## Xylem vessels showing different types of lignified thickening



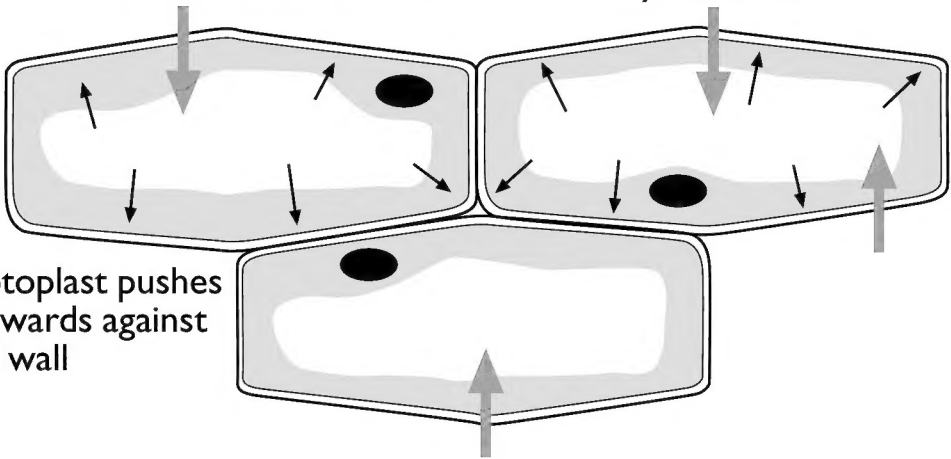


### Turgid Cells

Surrounding solution has lower water potential than protoplast

Water taken in by osmosis

Protoplast pushes outwards against cell wall



### Plasmolysed Cells

Surrounding solution has higher water potential than protoplast

Water lost by osmosis

Protoplast shrinks away from the cell wall

